

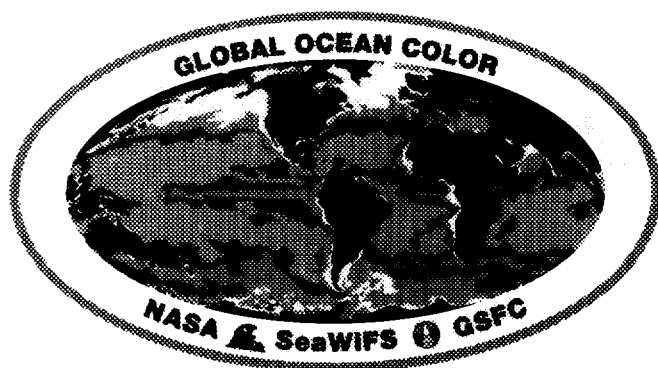
NASA Technical Memorandum 104566, Vol. 38

SeaWiFS Technical Report Series

Stanford B. Hooker and Elaine R. Firestone, Editors

Volume 38, SeaWiFS Calibration and Validation Quality Control Procedures

**Charles R. McClain, Michael Darzi, Robert A. Barnes, Robert E. Eplee, James K. Firestone,
Frederick S. Patt, Wayne D. Robinson, Brian D. Schieber, Robert H. Woodward, and
Eueng-nan Yeh**



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*NASA Goddard Space Flight Center
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PREFACE

The scope of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Calibration and Validation Program encompasses a broad variety of topics, as shown by numerous volumes (of so-called *case studies*) in the *SeaWiFS Technical Report Series* which are in a chapter format. Each case studies volume contains several chapters discussing topics germane to the Calibration and Validation Program. Although this document, Volume 38, is not a case studies volume per se, it further demonstrates both the breadth and complexity of the issues that the Program must address, and provides further justification for a comprehensive calibration and validation effort.

The chapters in this volume present discussions of:

- a) Engineering data display and quality control;
- b) SeaWiFS calibration verification;
- c) Quality control of SeaWiFS ancillary data;
- d) SeaWiFS data quality control software; and
- e) SeaWiFS derived product validation software.

Greenbelt, Maryland
September 1995

—C.R.M.
Project Scientist

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ABSTRACT

This document provides five brief reports that address several quality control procedures under the auspices of the Calibration and Validation Element (CVE) within the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project. Chapter 1 describes analyses of the 32 sensor engineering telemetry streams. Anomalies in any of the values may impact sensor performance in direct or indirect ways. The analyses are primarily examinations of parameter time series combined with statistical methods such as auto- and cross-correlation functions. Chapter 2 describes how the various onboard (solar and lunar) and vicarious (*in situ*) calibration data will be analyzed to quantify sensor degradation, if present. The analyses also include methods for detecting the influence of charged particles on sensor performance such as might be expected in the South Atlantic Anomaly (SAA). Chapter 3 discusses the quality control of the ancillary environmental data that are routinely received from other agencies or projects which are used in the atmospheric correction algorithm (total ozone, surface wind velocity, and surface pressure; surface relative humidity is also obtained, but is not used in the initial operational algorithm). Chapter 4 explains the procedures for screening level-1, level-2, and level-3 products. These quality control operations incorporate both automated and interactive procedures which check for file format errors (all levels), navigation offsets (level-1), mask and flag performance (level-2), and product anomalies (all levels). Finally, Chapter 5 discusses the *match-up* data set development for comparing SeaWiFS level-2 derived products with *in situ* observations, as well as the subsequent *outlier* analyses that will be used for evaluating error sources.

PROLOGUE

The experience gained with the Coastal Zone Color Scanner (CZCS) has had a definitive impact on the responsibilities of the Calibration and Validation Element (CVE) within the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project (McClain et al. 1992). As a result, the SeaWiFS Project has gone to great lengths to implement and document a multifaceted program that addresses sensor calibration, bio-optical and atmospheric correction algorithm development, and product quality control and validation. The present structure of the program and the team members are shown in Fig. 1. It includes the elements responsible for:

- 1) Determining the SeaWiFS sensor performance;
- 2) Field programs to collect high quality bio-optical data;
- 3) Bio-optical data processing and archiving; and
- 4) Software development in support of the operational data processing.

Through a series of meetings, the Project has worked closely with the SeaWiFS Science Team (SST) subgroups to define and review the algorithms for sensor calibration, atmospheric correction, and derived products. Also, the Project has worked closely with the SeaWiFS Data Analysis System (SeaDAS) development group, funded separately by the National Aeronautics and Space Administration (NASA) Headquarters Marine Biogeochemistry Program, to provide a processing capability available to the SeaWiFS user community. Many of the *SeaWiFS Technical Report Series* volumes are the result of work performed

under the CVE, especially in the first three areas listed above.

Because many of the studies and development efforts under the auspices of the CVE are not extensive enough to require dedicated volumes of the *SeaWiFS Technical Report Series*, the CVE has decided to publish volumes composed of brief, but topically specific, chapters. Three of these volumes have been termed *Case Studies* and include Volumes 13, 19, and 27. Volume 28 deals with the mask and flag algorithms, the sensor calibration algorithm, and a sensor stray light correction algorithm. This volume, Volume 38, addresses aspects of the CVE primarily associated with: items 1 and 4 (above), the initial operational procedures for tracking sensor performance, and derived product quality after launch. A short synopsis of each chapter in this volume is given below.

1. Engineering Data Display and Quality Control

The SeaWiFS data stream includes 32 engineering data fields, which in total provide an indication of the SeaWiFS instrument's state of health during the mission. This chapter describes the significance of these data, the methods for their processing and archiving by the Project, and software applications built for displaying and quality controlling these data. The software provides for generating statistics on a scene, latitude zone, or solar zenith angle basis. The statistics, or raw scene-level engineering data, can be displayed.

2. SeaWiFS Calibration Verification

The SeaWiFS CVE has undertaken a program to monitor the radiometric response of the SeaWiFS instrument

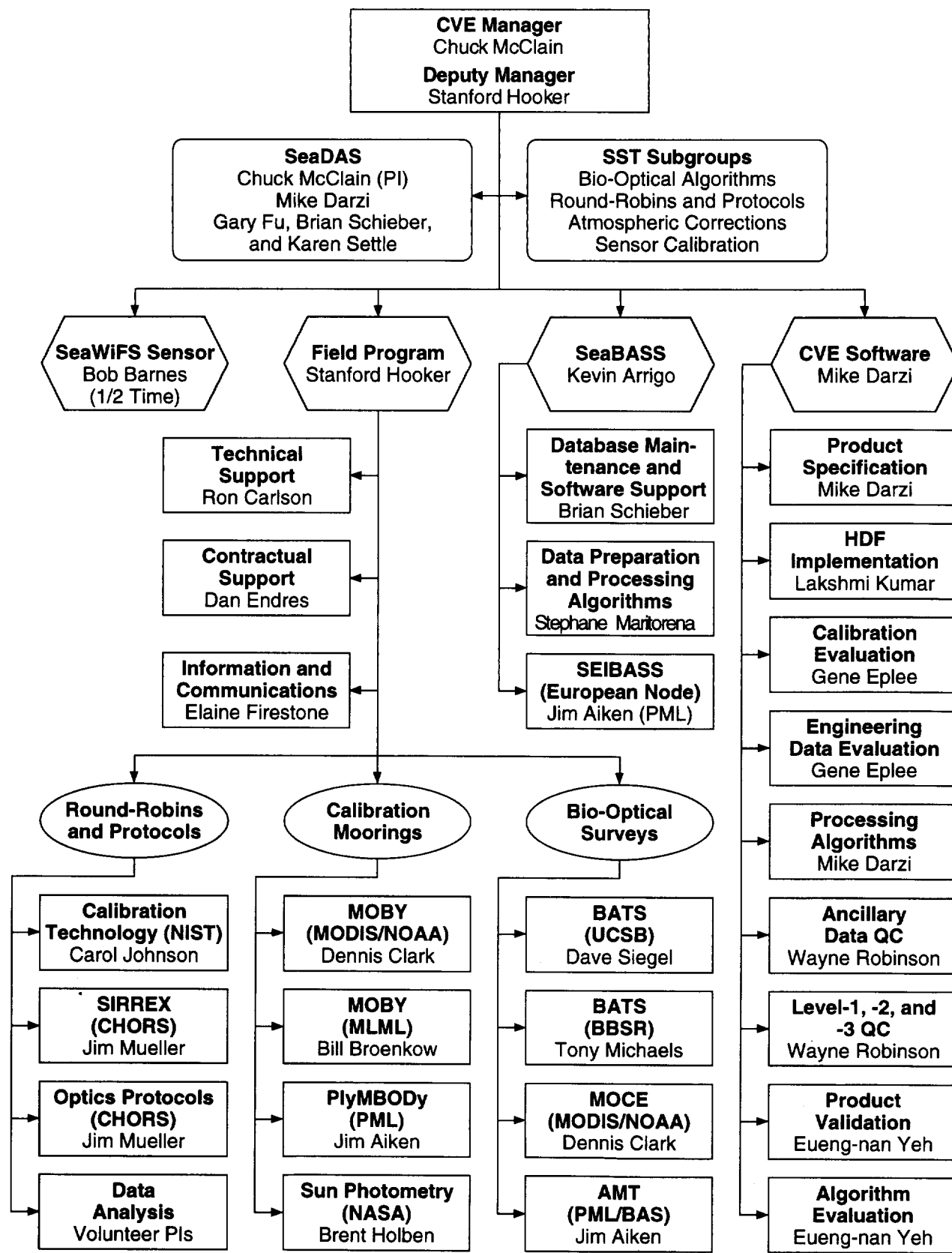


Fig. 1. This CVE organization chart is an updated version of the one presented at the August, 1995, review.

over the course of its five-year ocean color mission. This program will employ a combination of on-orbit calibration, *in situ* calibration, and sensor characterization techniques to track sensor performance. The procedures and data sets that comprise the calibration verification program will be described in this chapter.

3. *Quality Control of SeaWiFS Ancillary Data*

Processing SeaWiFS data requires the use of external, i.e., ancillary, data products to derive the set of SeaWiFS standard geophysical (level-2) parameters. Ancillary meteorological data products of total column ozone and surface values of zonal and meridional wind speed, atmospheric pressure, and possibly relative humidity or total precipitable water, will be used in the level-2 processing. These ancillary data files are provided by the National Meteorological Center (NMC) and the Television Infrared Observing Satellite (TIROS) Operational Vertical Sounder (TOVS) project; equivalent products may be obtained from other sources.

The CVE has developed procedures and software to assure the quality of the input products processed using the SeaWiFS Data Processing System (SDPS). Ancillary data files are converted to a SeaWiFS defined specification and stored in the Hierarchical Data Format (HDF). The HDF data undergo quality control (QC) procedures using both noninteractive and interactive programs to assess their validity. The data are then used for level-2 processing and are distributed to the research community through the

Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC). This chapter describes the approaches to QC of SeaWiFS ancillary files through software used by the SeaWiFS Project.

4. *SeaWiFS Data Quality Control Software*

This chapter presents the procedures and software employed to monitor and control the quality of the geophysical data from the SeaWiFS instrument aboard the SeaStar satellite. The quality control programs consist of a set of automated programs which verify that the data conforms to broad statistical guidelines, and interactive programs that allow for more in-depth investigation of problems, as well as a final level of approval for the data. The QC programs are applied to the data in all three stages of processing: level-1a, level-2, and level-3. The procedures for the efficient use of these programs are also discussed.

5. *SeaWiFS Derived Product Validation Software*

The SeaWiFS derived product validation software was developed to compare SeaWiFS level-2 data with *in situ* data in order to assist in evaluating the sensor performance and the accuracy of the level-2 algorithms. The software will be used as part of an effort that will proceed continuously after launch to verify that the data generated by the SeaWiFS Project for archiving and distributing meet the required accuracy. The software will also be used to test algorithms alternative to those used operationally. An overview of this derived product validation software and its use is presented herein.

Chapter 1

Engineering Data Display and Quality Control

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ABSTRACT

The SeaWiFS data stream includes 32 engineering data fields, which in total provide an indication of the SeaWiFS instrument's state of health during the mission. This chapter describes the significance of these data, the methods for their processing and archiving by the Project, and software applications built for displaying and quality controlling these data. The software provides for generating statistics on a scene, latitude zone, or solar zenith angle basis. The statistics, or raw scene-level engineering data, can be displayed.

1.1 INTRODUCTION

SeaWiFS is an ocean color instrument—its primary measurements are ocean-leaving radiances that have passed through the top of the atmosphere. As with other Earth observing satellite instruments, SeaWiFS will be used to detect short- and long-term changes in the condition of the planet. It is critically important, however, to distinguish geophysical changes in the Earth-exiting radiances from apparent changes that will result from the aging of the sensor on orbit. The SeaWiFS Project has initiated a program of onboard and vicarious measurements to detect the magnitude of instrumentally-based changes in the SeaWiFS radiances during the sensor's on-orbit life.

The QC programs for SeaWiFS engineering data will be used to gain an understanding of internal changes in the sensor and to provide relationships between these internal changes and changes in SeaWiFS radiances. To do this, the CVE will compile the engineering data stream from the instrument for each scene and provide a continuous and automatically updated set of statistics about these data. The engineering data QC software will have the capability of notifying SeaWiFS Mission Operations if engineering parameters exceed established limits. The principal design of the software has been for interactive analysis of engineering data to detect 1) trends in the along track values during an orbit as the spacecraft encounters varying thermal and radiation environments, and 2) long-term trends

in average values (e.g., orbit and zones of latitude and solar zenith angles), as system components age.

1.2 DATA PROCESSING

The SeaWiFS engineering telemetry data are transmitted in a packet consisting of 44 10-bit words (55 bytes), and are included in the data stream for two out of every three scan lines. (Note that the 44-word packet is transmitted with every scan line, but contains instrument telemetry for lines 1 and 3 for each set of three; the packet is not used currently for line 2.) The location and contents of the engineering telemetry are fully described in the SeaStar Spacecraft L-band and S-band Downlink Interface Control Documents [Orbital Sciences Corporation (OSC) internal documents]. In the local area coverage (LAC) and High Resolution Picture Transmission (HRPT) data streams, the packet appears in the minor frame immediately after the spacecraft telemetry and before the gain and time delay and integration (TDI) words. In the global area coverage (GAC) data, the five packets corresponding to the five scan lines appear in the minor frame following the scan line data.

The 44 words of engineering data are allocated as follows:

- Words 1–4 represent an instrument time tag.
- Words 5–7 are used for instrument discrete telemetry; 22 of the bits are used to represent the instru-

Table 1. Engineering telemetry parameters and scaling for SeaWiFS. The table includes absolute limits and *Red Limits* for the operation of SeaWiFS.

Analog Telemetry Point	Conversion		Absolute Limits		Red Limits	
	Slope	Intercept	Low	High	Low	High
Band 1/2 FPA ¹ Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Band 3/4 FPA Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Band 5/6 FPA Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Band 7/8 FPA Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Telescope Motor Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Tilt Base Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Tilt Platform Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Half-Angle Motor Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Power Supply-A Input Current ²	0.02	0.26	0.26	5.36	1.0	3.0
Power Supply-B Input Current ²	0.02	0.26	0.26	5.36	1.0	3.0
+15 V Analog Power Voltage ³	0.075	0.0	0.0	19.125	15.0	15.5
-15 V Analog Power Voltage ³	-0.075	0.0	-19.125	0.0	-15.5	-15.0
+5 V Logic Power Voltage ³	0.025	0.0	0.0	6.375	4.9	5.6
Power Supply Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
B1/B2 Post-Amplifier Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
Servo Driver Temperature	-0.2667	66.667	-1.334	66.667	5.0	45.0
+30 V Servo Power Voltage ³	0.15	0.0	0.0	38.25	28.5	31.0
+21 V Servo Power Voltage ³	0.1044	0.0	0.0	26.622	20.0	22.0
-21 V Servo Power Voltage ³	-0.1044	0.0	-26.622	0.0	-22.0	-20.0
+5 V Servo Power Voltage ³	0.025	0.0	0.0	6.375	4.9	5.6
Angular Momentum Speed ^{3,4}	8.52	-377.0	-377.0	1795.6	1215.0	1255.0
Tilt Platform Position ³	1.44	0.0	0.0	367.2	0.0	360.0
Tilt Base Position ³	1.44	0.0	0.0	367.2	0.0	360.0
+28 V Heater Power ³	0.14	0.0	0.0	35.7	27.0	29.0
Telescope-A Motor Current ^{3,5}	0.0024	0.0	0.0	0.612	0.1	0.4
Telescope-B Motor Current ^{3,5}	0.0024	0.0	0.0	0.612	0.1	0.4
Half-Angle-A Motor Current ^{3,5}	0.0024	0.0	0.0	0.612	0.1	0.4
Half-Angle-B Motor Current ^{3,5}	0.0024	0.0	0.0	0.612	0.1	0.4
Servo-A Phase Error ^{3,5}	0.01	-1.25	-1.25	1.25	-1.0	1.0
Servo-B Phase Error ^{3,5}	0.01	-1.25	-1.25	1.25	-1.0	1.0
Angular Momentum Compensation A-Motor Current ^{3,4,5}	0.016	0.0	0.0	4.08	0.08	0.6
Angular Momentum Compensation B-Motor Current ^{3,4,5}	0.016	0.0	0.0	4.08	0.08	0.6

1. Focal Plane Assembly

2. This parameter is dependent upon the choice of power supply. (It does not appear in the instrument discrete telemetry, so it is assumed to be a spacecraft field.)

3. This parameter is dependent upon the analog power on.

4. This parameter is dependent upon the angular momentum compensation on.

5. This parameter is dependent upon the choice of servo-A or -B.

ment state (for example, Earth or solar mode, tilt status, or half-angle mirror side) with 8 pads or spare bits.

- Words 8–39 contain the 32 analog telemetry fields, one field per word.
- The remaining five words are spares.

Each of the 32 analog telemetry words contains a physical quantity which has been scaled to an 8-bit integer value for transmission in the data stream; the data are padded to 10 bits. The types of sensor measurements are shown in Table 1 and include: temperatures, voltages, and currents for various sensor components; sensor tilt angle measure-

ments; angular rate of the momentum compensator; and servo phase errors (McClain et al. 1995).

Each measurement type in Table 1 has a linear conversion (slope plus intercept) to physical units. The temperature conversions, which are nonlinear, are approximated by the linear conversion with sufficient accuracy for limit checking. Units are in degrees Celsius (temperature), volts (voltage), amperes (current), or degrees of rotation (position and error). The 8-bit data results in an absolute measurement range; in addition, most measurements have a more restricted range for safe operation. The upper and lower limits of the safe operating range are referred to as *red limits*; scan lines with readings outside of these lim-

its indicate a high probability of a sensor problem and are flagged in the level-2 SeaWiFS products (McClain et al. 1995). It is also important to note that some telemetry points have "A" and "B" settings, corresponding to opposite mirror sides; in this case, only one side will be active at a time, and this will be indicated by a bit in the discrete telemetry.

The SDPS level-0 to level-1a processing software unpacks and converts the instrument telemetry and stores them in the level-1a data product. The analog telemetry are converted and stored in a floating point array, and the discrete telemetry are unpacked into a byte array (one status bit per byte). The full set of data is stored for each scan line in the level-1a product. The data are also written to a separate (nonarchive) instrument telemetry file for off-line analysis. In addition, the software performs limit checking on the analog telemetry using the limits in Table 1, and stores a summary of the data quality as metadata in the products.

The SDPS level-0 to level-1a processing software also computes a set of quality metrics for the eight bands of the level-1a data files. These metrics computed for each band in the scene are as follows: the number of saturated pixels, the number of unsaturated pixels, the number of zero pixels, and the mean radiance in counts. The additional metrics computed are the number of scan lines in the scene, the number of zero-filled (missing) scan lines in the scene, and the number of missing minor frames in the scene. These metrics are stored as metadata in the level-1a products.

1.3 ANALYSIS SOFTWARE

To facilitate the continuous monitoring of instrument health and safety during the SeaWiFS mission, two software applications have been written using the Interactive Data Language (IDL) from Research System, Inc.: `ORBSTAT.PRO` and `TELEMETRY.PRO`.

The `ORBSTAT.PRO` program computes engineering data statistics for an entire scene, or a specified range of latitude or solar zenith angle within the scene. The program is run automatically, so the statistics are generated as soon as the telemetry is available. During statistics generation, the individual engineering values within the scene will be compared with the red limits described in Section 1.2. Any values falling outside of the red limits will be logged to a file residing on the SeaWiFS CALVAL computing system, and the Mission Operations element will be notified of the deviations through electronic mail after the scene is processed. Mission Operations may then choose to notify OSC if the problems persist, so that OSC is aware of potential instrument anomalies.

The `ORBSTAT.PRO` program requires as input a value representing the field to use for generating zonal statistics (LAT for latitude or SZA for solar zenith angle) and the increment to be used in defining the statistics zones, e.g., 10°

of latitude or zenith angle. If a negative number is entered for the zone increment, the zone type is ignored and statistics are computed for the entire contents of each level-1a SeaWiFS file, i.e., scene. If the statistics zone increment is positive, the value is assumed to be an increment of either latitude or solar zenith angle. Statistics (mean, standard deviation, and number of observations) are then computed and written to either new American Standard Code for Information Interchange (ASCII) statistics files or appended to existing ones. The statistics files are given unique names which include the zone type (entire scene, solar zenith angle, or latitude), data type [GAC, LAC, solar, lunar, TDI, intergain calibration (IGC), or HRPT], and engineering field name (e.g., focal plane temperature).

When statistics by latitude zone have been requested, north and south extents are computed which entirely encompass the scene for the requested latitude increment. The northern extent is defined to be the nearest 10° increment north of the northern terminus of the scene. The zones for statistics generation are then defined by applying the increment southward from the northern extent, to encompass the southern extent. The individual level-1a HDF scenes are read, and the individual points along the scene are scanned. Those that fall within particular latitude zones between the northern and southern extents are included in the statistics for that zone.

Statistics can also be generated by increments of the solar zenith angle. In a manner similar to that used for latitude, zones of solar zenith angles are defined which encompass the entire scene in each file. Only values within the scene having solar zenith angles within one of the computed angle ranges will be included in that range's statistics.

The files containing statistics for either latitude or solar zenith angle zones will be ordered chronologically by time. For each time, there is a second level of ordering by zone (latitude or zenith angle) in a decreasing sense. A given statistics file contains values for a particular field in the engineering data. The files containing statistics by scene are also ordered chronologically by time, with one line containing the statistics for each time. For all of the files, the values written to each line are: year, sequential day of the year, time, orbit number for the current sequential day, total number of orbits for the current sequential day, spatial or angle range, data mean, data standard deviation, and the number of elements used in computing mean and standard deviation. The spatial range includes northern latitude and longitude extents followed by the southern latitude and longitude extents, relative to the entire scene or current latitude increment. (Note that these extents are not necessarily on the latitude increment boundaries but reflect the actual data locations along the orbit.) The angle range, if present, lists the minimum followed by the maximum solar zenith angle for the current increment.

The `ORBSTAT.PRO` program compiles the data quality metrics for each level-1a input file into corresponding metrics tracking files. These tracking files contain one entry

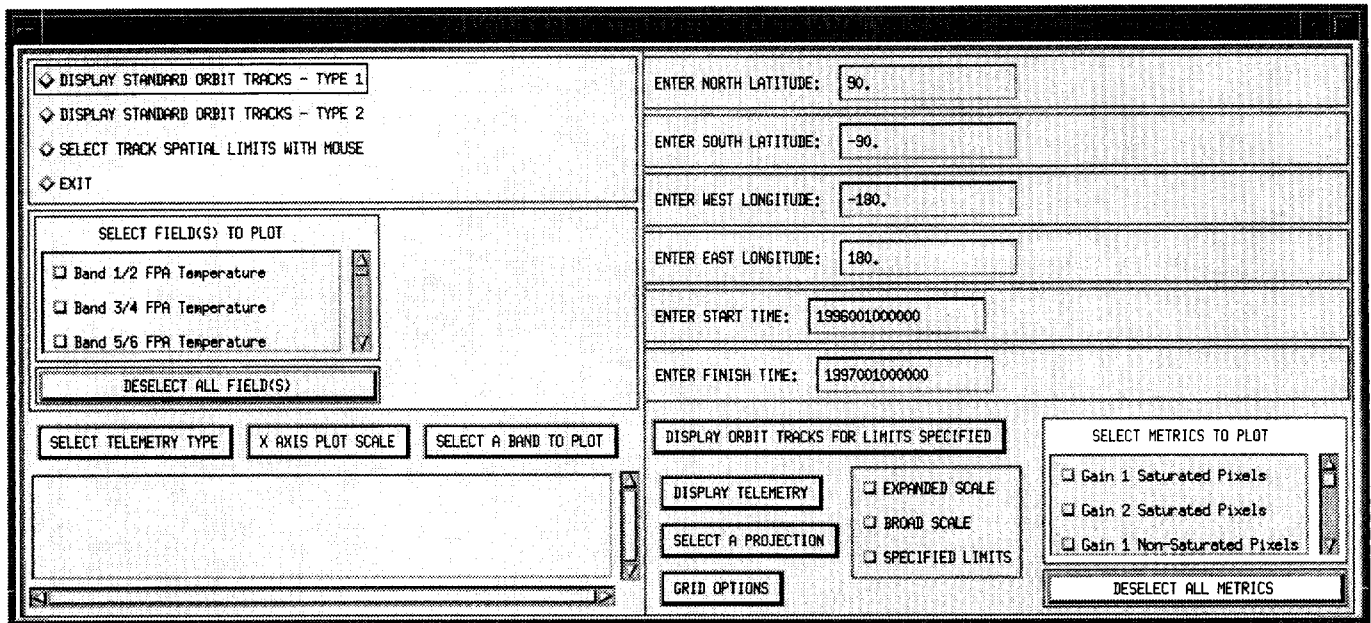


Fig. 2. This is the main display for the TELEMETRY.PRO program.

line for each level-1a file, arranged in chronological order. Each line in the file contains the start time of the level-1a file and the metrics for each band. In order to avoid duplicate entries in the tracking files, the data quality metrics are updated only when ORBSTAT.PRO is run solely with the latitude option.

The TELEMETRY.PRO program is based on an IDL graphical user interface (GUI) for displaying and analyzing the statistics generated by ORBSTAT.PRO and the raw engineering data values or satellite tracks within SeaWiFS level-1a HDF scenes. Figure 2 illustrates the main display screen appearing after TELEMETRY.PRO is started. The screen allows the user to define the criteria for the data or satellite tracks to be displayed:

- Spatial and temporal limits,
- Engineering data fields,
- Telemetry type,
- Plot scales,
- The number of scenes to include in the plots, and
- The characteristics of background maps including projection and grid type.

The following notes summarize pertinent information regarding the criteria:

Spatial Limits: This can be specified either by choosing the option SELECT TRACK SPATIAL LIMITS WITH MOUSE, whereby the user marks out an area of interest with a mouse, or by explicitly entering the limits in the text boxes ENTER NORTH LATITUDE, ENTER SOUTH LATITUDE, etc.

Temporal Limits: The default start time for data selection is 24 hours prior to the current time, and the default end

time is the current time. The start and end times are displayed when the interface starts, in the ENTER START TIME and ENTER FINISH TIME text boxes. The user can choose to change one or both of these values by manually entering new ones.

Engineering Data Fields: The scrollable widget SELECT FIELDS TO PLOT contains an entry for each of the 32 SeaWiFS engineering fields. When creating data plots, the user must choose one or more of the fields by clicking on the line containing each field of interest. At any time, the current list can be cleared by pressing the DESELECT ALL FIELD(S) button under the scrollable widget.

Data Quality Metric Fields: The scrollable widget entitled SELECT METRICS TO PLOT contains an entry for each of the 11 data quality metric fields. When creating data plots, the user must choose one or more of the fields by clicking on the line containing each field of interest. At any time, the current list can be cleared by pressing the DESELECT ALL METRICS button under the scrollable widget.

Telemetry Type: The SELECT TELEMETRY TYPE button, when pressed, displays a pull-down menu containing the possible types of scenes for processing. The list includes GAC, LAC, SOL (solar), LUN (lunar), TDI, IGC, and HRPT. If the pull-down menu is not accessed, the telemetry type defaults to GAC. The telemetry type selected serves to limit the subset of scenes to be processed from the archive directory, i.e., only the set with the given telemetry type will be included for further processing.

Band to Plot: The SELECT A BAND TO PLOT button, when pressed, allows the user to select one of the eight bands in order to plot data.

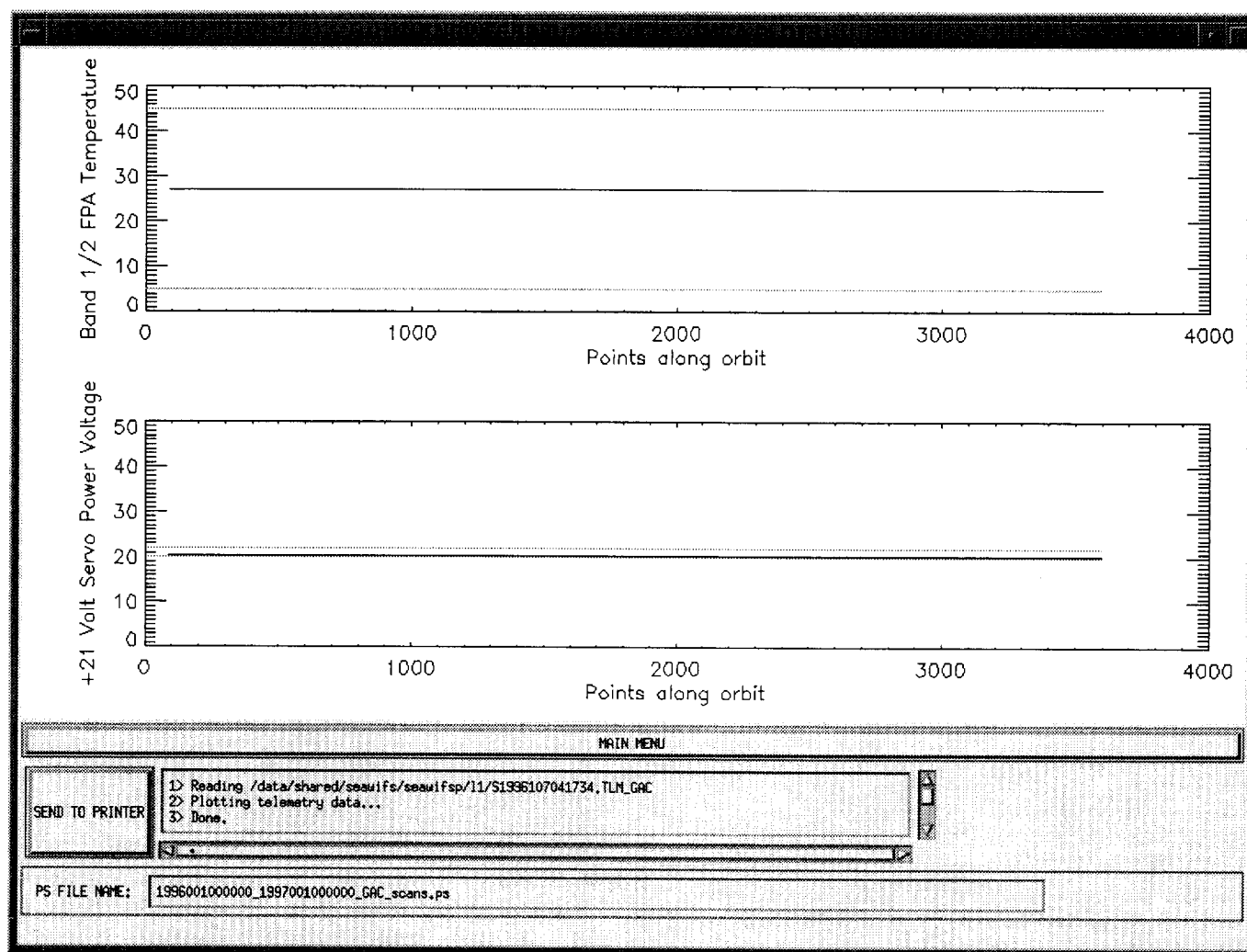


Fig. 3. This is the telemetry data display for the TELEMETRY.PRO program.

Plot Scales: The default abscissa plot scale for telemetry data plots is POINTS ALONG ORBIT, that is, simply a sequential counter within the satellite scene. The user can choose an abscissa of latitude via the X-AXIS PLOT SCALE button. For the ordinate scale, the default is a scale encompassing not only the actual data limits, but the red limits for the telemetry field as well (listed as BROAD SCALE in the menu next to the DISPLAY TELEMETRY pull-down menu). The user can also choose an EXPANDED SCALE which encompasses only the actual data limits. Finally, the user can choose SPECIFIED LIMITS, which results in a prompt for the minimum and maximum scale values to use.

Scenes to Include in Plots: For either display of satellite tracks or of telemetry data, the user can specify the number of scenes to include in the output. For satellite track display, the DISPLAY ORBIT TRACKS FOR LIMITS SPECIFIED pull-down menu is used. The user can specify that a single scene's data be displayed on each plot, that all scenes in the specified spatial range be displayed, or that individual scenes be displayed and not erased as new ones are

added in sequence. For the single scene option, the user must select a filename from a selection widget containing all scenes within the desired temporal limits and telemetry type. The appropriate track, or tracks, is displayed immediately following scene selection.

For telemetry data or data quality metric display, the DISPLAY TELEMETRY pull-down menu is pressed and has a similar set of choices as the satellite track display. The primary difference is that, for sequencing through scenes, there are two menu choices: using common scaling (i.e., the ordinate limits are chosen to encompass limits over all scenes in the plotting subset) or using independent scaling (i.e., the ordinate will vary with each scene in the sequence). The actual limits to appear on each plot will be tied to the selection of expanded, broad, or specific scaling. All but the last three selections in the pull-down menu refer to plots of the raw telemetry data. The DISPLAY DATA QUALITY METRICS selection plots the data quality metric data. The last two selections, DISPLAY STATISTICS

BY LATITUDE ZONE and DISPLAY STATISTICS BY ZENITH ANGLE ZONE, allow the user to plot a time series of statistics by zones of latitude or the solar zenith angle within a scene (the user chooses the file containing the statistics from a scrollable list).

Projections: With the **SELECT A PROJECTION** button, the user can select any of 12 specified map projections supported by IDL to serve as the background map base for satellite track plotting. The default is a cylindrical equidistant map.

Grid Types: By default, no grid is placed on the satellite track map; however, the user can choose to have a grid plotted, either with or without continental boundaries, with the **GRID OPTIONS** button.

Figure 3 illustrates a sample screen resulting from a plot of the band 1/2 focal plane temperature and +21 V

servo power voltage for an entire scene. On the plot, the lines at 5° and 45° for temperature, and approximately 20.5 V and 21.5 V for servo power voltage, represent the red limits, while the other lines are the actual data (set to a constant for the test data set used as input). Note the button marked **SEND TO PRINTER**. The user can press this to obtain a hard copy of the displayed screen on the default printer. Next to the pull-down menu is a scrollable widget listing the actions performed in preparing the displayed plot. Under the button and scrollable widget is a text widget indicating a default filename to contain a PostScript representation of the displayed plot. The default name uses the start and end data times, as well as the telemetry type and indicator for whether the data falls within a scan (`_scans.ps`) or represents statistics across multiple scenes (`_scene.ps`). The PostScript file is saved to the user's current directory whenever a plot is sent to the printer.

Chapter 2

SeaWiFS Calibration Verification

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ABSTRACT

The SeaWiFS CVE has undertaken a program to monitor the radiometric response of the SeaWiFS instrument over the course of its five-year ocean color mission. This program will employ a combination of on-orbit calibration, *in situ* calibration, and sensor characterization techniques to track sensor performance. The procedures and data sets that comprise the calibration verification program are described in this chapter.

2.1 INTRODUCTION

SeaWiFS is an eight-band, visible and near-infrared radiometer with a spatial resolution of 1.1 km at nadir (Hooker et al. 1992). SeaWiFS is a follow-on instrument to the CZCS which operated from 1978–86 aboard NIMBUS-7. The goal of the SeaWiFS Project, based at NASA GSFC, is to produce a five-year ocean color data set with a 5% absolute and 1% relative radiometric accuracy (McClain et al. 1992). The extensive effort to calibrate and characterize the instrument prior to launch has been documented in Barnes et al. (1994a and 1994b), and Biggar et al. (1994 and 1995).

As part of the quality control process of the SeaWiFS archive data products, the CVE will perform a series of extensive calibration verification procedures to monitor the SeaWiFS instrument's response over the course of the mission, using a combination of vicarious (based on *in situ* observations) and onboard calibration techniques. This effort addresses problems encountered in calibrating CZCS, wherein the internal calibration, which is based on calibration lamps, proved to be unreliable. This limitation required the application of a vicarious calibration technique which assumed constant mean normalized water-leaving radiances (L_{WN}) at 520 and 550 nm for clear water in the global ocean (Evans and Gordon 1994). While this restriction may not have been serious for CZCS, given that it was a proof-of-concept mission, it undermines the objectives of the SeaWiFS mission. Consequently, SeaWiFS will use imagery of the moon, data from a solar-illuminated diffuser plate, and a mission-long field program to track the sensor

performance. An overview of the calibration verification strategy is shown in Fig. 4.

The calibration verification effort has four major areas of concern in assessing the performance of SeaWiFS:

- 1) Determining the stability of the radiometric calibration of the instrument;
- 2) Evaluating the atmospheric correction of the level-2 (L2) data at the vicarious calibration sites;
- 3) Characterizing any on-orbit changes in the instrument state of health; and
- 4) Investigating the influence of the South Atlantic Anomaly (SAA) on the instrument and data.

The CVE will address these areas by analyzing the following data sets:

- a) Lunar calibration data taken once per month when the moon is at a phase of 7°;
- b) Solar diffuser calibration data taken approximately once per week while the spacecraft is over the South Pole;
- c) L2 LAC scenes taken over vicarious calibration sites (that is, marine optical buoys and high altitude calibration sites), along with contemporaneous *in situ* data from those sites;
- d) Level-3 (L3) global distributions of normalized water-leaving radiances for clear water;
- e) On-orbit detector, gain, and mirror-side calibration data;
- f) Spacecraft telemetry data; and
- g) On-orbit dark count data.

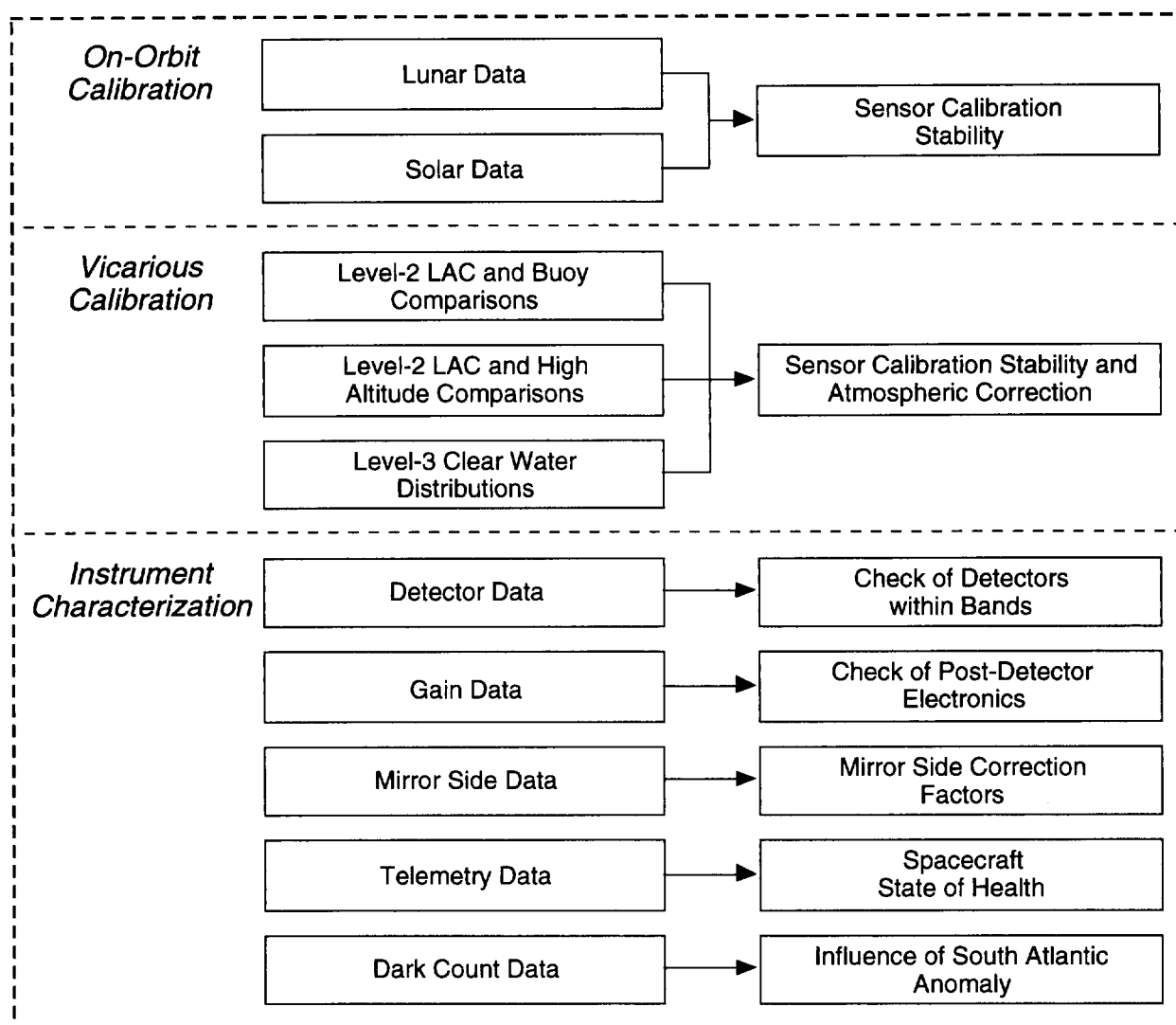


Fig. 4. This figure shows the calibration verification strategy for SeaWiFS. On-orbit calibration, vicarious calibration, and sensor characterization data sets will be analyzed to assess the sensor calibration stability, the atmospheric correction algorithm, and the on-orbit instrument state of health.

Merged analyses of the lunar and solar calibration data, the L2 LAC vicarious data comparisons, and the L3 clear-water distributions will allow evaluations of the sensor calibration stability and the atmospheric correction to be made.

2.2 AT-SENSOR RADIANCES

The calibration verification strategy requires that several of the level-1 data sets (lunar, solar, detector, and gain data) are calibrated to *at-sensor* or *top of the atmosphere* radiances. These level-1b (L1b) data products are generated from operational level-1a (L1a), or raw, data files by the application of the sensor calibration model (Darzi et al. 1995) and have units of $\text{mW cm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$. The L1b data sets are produced for calibration verification purposes and are not part of the SeaWiFS standard op-

erational products. The data flow diagram for processing L1b data is shown in Fig. 5.

2.3 ON-ORBIT CALIBRATION

Lunar and solar observations provide the primary way of tracking the long-term radiometric sensitivity of the SeaWiFS instrument (Woodward et al. 1993).

2.3.1 Lunar Calibration

Lunar calibrations will be performed about once per month when the moon is at a phase of 7° by pitching the spacecraft across the moon and integrating the signal across the lunar disk. The phase angle of 7° is chosen to maximize the illuminated surface of the moon while minimizing the effects of the opposition effect, the surge in

brightness of the light diffusely reflected from a surface near zero phase [see Hapke (1986) for a discussion of the opposition effect]. Two methods will be employed to track the instrument response using the lunar data:

- 1) Comparing the integrated lunar radiance with the predicted lunar radiances from a photometric lunar model developed to calibrate the SeaWiFS instrument and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor (Kieffer and Wildey 1996); and
- 2) Normalizing the integrated lunar radiance to a common sun-moon distance of one Astronomical Unit (AU), a common SeaWiFS-moon distance of one mean Earth-moon distance, and a common lunar phase angle of 7° .

The data flow diagram for processing lunar observations is shown in Fig. 6.

The first method uses the time of the calibration and the position of the spacecraft at that time to compute model radiances for the moon in the eight SeaWiFS bands. Variables in the photometric model include the sun-moon distance, the SeaWiFS-moon distance, the phase of the moon, and libration (or wobble) in the moon's motion. The second method normalizes the integrated radiances over all of these parameters, except libration, to achieve a uniform data set; libration will give rise to a periodic variation in the normalized radiances. Method one will be the primary monitor, while method two will provide a check on the gross properties of the photometric model. These two sets of lunar radiances, which should track each other, will provide a model-independent time series to monitor the radiometric calibration of the instrument.

During lunar calibrations, SeaWiFS views the moon in the same fashion that it views the Earth; however, there is a complication in processing lunar data that does not occur for any other data type. For Earth observations, the pitch rate of the spacecraft matches its ground track speed so that adjacent scan lines in a scene observe adjacent ground swaths. During lunar calibrations, the pitch rate of the spacecraft is slower than its lunar track speed, so the moon is oversampled. Consequently, the lunar radiances must be scaled by a pitch rate-dependent correction factor to compensate for this oversampling. These scaled radiances are compared to the photometric model in method one and are then normalized for use in method two.

2.3.2 Solar Calibration

Solar calibrations will be performed at shorter intervals between lunar calibrations, typically on a weekly basis, to provide a more frequent calibration reference. The observations will record sunlight reflected by a uniformly illuminated solar diffuser plate while the spacecraft is over the South Pole. The solar data will be normalized to a common sun-Earth distance of one AU for analysis. The data

flow diagram for processing solar observations is shown in Fig. 7.

One set of parameters that is required for processing solar data is the location of the diffuser plate in the scan path of the instrument. Initially, these pixel indices are determined from solar scans obtained as part of the preflight solar-based calibration of SeaWiFS (Biggar et al. 1995). These indices will be revised, if necessary, based on the initial on-orbit solar calibrations.

A time series analysis of the solar data should show two trends. The first is a periodic variation in the bidirectional reflectance distribution function (BRDF) of the diffuser plate as the image of the sun moves seasonally across the plate. The second trend is a slow exponential degradation with time as photolyzed organic materials, outgassed from the spacecraft, condense onto the surface of the diffuser. This degradation can be approximated by a piecewise linear function between lunar calibrations. The solar data will be normalized by the lunar observations to correct for the degradation. A by-product of this process will be a model of the solar diffuser degradation. The merged solar and lunar calibration data will provide an on-orbit calibration time series for monitoring the sensor calibration stability (Gordon 1987).

2.4 VICARIOUS CALIBRATION

There are two main methods of vicariously calibrating the SeaWiFS data:

1. Comparing L2 LAC scenes with *in situ* buoy measurements, and
2. Analyzing global distributions of normalized water-leaving radiances for clear water.

2.4.1 L2 LAC and Buoy Comparisons

The primary method for the vicarious calibration of SeaWiFS will be to compare L2 LAC scenes over the Marine Optical Buoy (MOBY) with *in situ* observations from MOBY (McClain et al. 1992). MOBY will be located west of the Hawaiian island of Lanai in open ocean, Case-1 water with low pigment concentrations. Average normalized water-leaving radiances will be computed at the buoy site in the L2 LAC scenes. These radiances will be compared with radiances measured by MOBY at the time of the spacecraft overflight. Overflights will occur every other day. A significant percentage of the data will be lost to cloud cover, but over the course of the mission, a substantial data set will accumulate. A time series analysis of these comparison data will provide an *in situ* monitor of the calibration stability of the instrument.

The data flow diagram for comparing L2 LAC and MOBY data is shown in Fig. 8. The data quality flags used in processing the L2 LAC data will typically be the flags used in normal SeaWiFS data processing (McClain et al. 1995). An analysis of the dependence of the error in

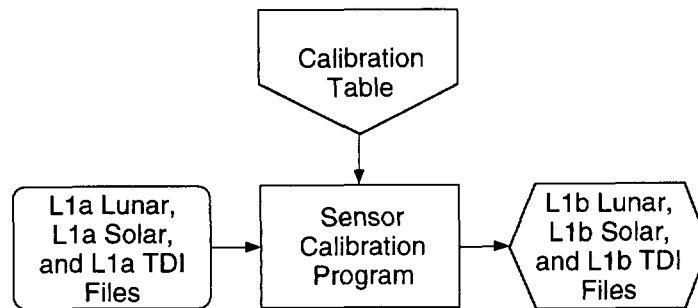


Fig. 5. This flow chart of sensor calibration shows that level-1b data products are produced by applying the sensor calibration model to level-1a data sets.

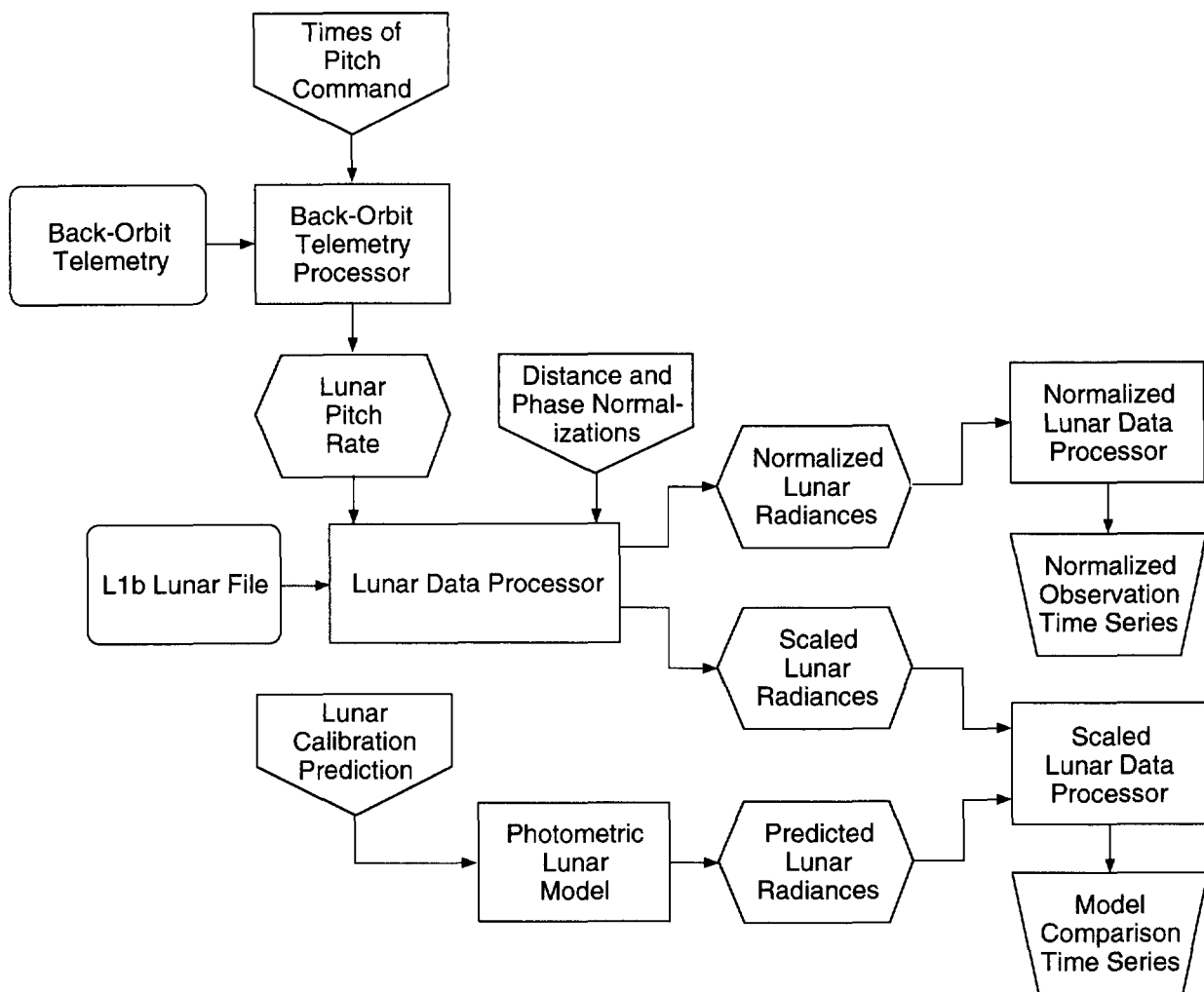


Fig. 6. This flow chart of lunar data processing shows that lunar radiances are compared with a photometric model and are normalized to a common observation state as independent methods of tracking the instrument response.

the L2 LAC scenes on the atmospheric optical path length of the spacecraft data will yield an evaluation of the atmospheric correction algorithm. This algorithm may break down for long optical paths. The data flow diagram for this analysis is shown in Fig. 9.

Similar vicarious calibration techniques will be used for any high-altitude calibration site, e.g., Lake Tahoe, that become active over the course of the mission.

2.4.2 L3 Clear-Water Distributions

A second method for the vicarious calibration of SeaWiFS will involve the computation of global distributions of clear water normalized water-leaving radiances. Clear water is defined here to be open ocean Case-1 water with a minimum depth of 1,000 m and low pigment concentrations. In this method, L2 GAC clear-water data are binned on a daily basis to the SeaWiFS L3 grid. The distribution of normalized water-leaving radiances is computed for each daily file. A time series analysis of these distributions will provide an additional *in situ* monitor of the instrument calibration stability.

The data flow diagram for processing the clear-water distributions is shown in Fig. 10. The data quality flags used in processing the L2 GAC data will be those required to select clear water. The L2 LAC and buoy comparison time series and the clear-water distribution time series will be compared and, if consistent, merged to produce an *in situ* calibration time series for monitoring the sensor calibration stability.

2.5 CALIBRATION EVALUATION

The combined analyses of the on-orbit and vicarious calibration data sets will yield evaluations of the SeaWiFS calibration stability and atmospheric correction.

2.5.1 Sensor Calibration Stability

The primary method for monitoring the calibration stability of SeaWiFS will be to merge the on-orbit and *in situ* calibration time series. An analysis of the merged time series will test for any trends in the instrument response. If trends are present, the CVE will recommend the incorporation of appropriate temporal correction factors into the SeaWiFS calibration table (Barnes et al. 1994b). The data flow diagram for merging the time series is shown in Fig. 11.

A second monitor of the calibration stability is a check on interband variations. The CVE will compute ratios of the calibration time series for pairs of bands. Color ratio time series will be generated for bands 1 and 2 (412 nm and 443 nm), for bands 2 and 3 (443 nm and 490 nm), for bands 2 and 5 (443 nm and 555 nm) and for bands 3 and 5 (490 nm and 555 nm), the primary band ratios used in the SeaWiFS bio-optical algorithms (Aiken et al. 1995 and Carder et al. 1996). Analysis of these time series will indicate whether

or not the sensitivities of individual bands are varying with respect to each other.

2.5.2 Atmospheric Correction

The comparison of the on-orbit and *in situ* time series prior to merger will test the atmospheric correction algorithm at the vicarious calibration sites: disagreement between the two time series will indicate a deficiency in the atmospheric correction of the L2 LAC data. This comparison of the two calibration time series, combined with the path length analysis of the L2 LAC and buoy data comparisons will yield an evaluation of the performance of the atmospheric correction algorithm.

2.6 SENSOR CHARACTERIZATION

The sensor characterization task of the calibration verification effort has two components:

1. Monitoring the instrument's state of health, and
2. Assessing the influence of the SAA on the SeaWiFS data.

2.6.1 Sensor State of Health

The on-orbit sensor characterization will look for changes in the instrument's state of health over the course of the mission. Several data sets will be collected on a routine basis for this purpose (Woodward et al. 1993).

Detector calibration data, or TDI data, will be recorded on orbits immediately following solar calibrations by varying detector sequences for each band while observing the solar diffuser plate. Radiance ratios will be computed for the different detector sequences. A time series analysis of these ratios will indicate any changes in the detectors within each band. The data flow diagram for processing TDI data is shown in Fig. 12. As with solar data, the location of the diffuser plate within the scan path of the instrument is required for processing TDI data.

Gain calibration data will be collected immediately following solar calibration or TDI calibrations by varying the detector gain settings while injecting a fixed signal into the postdetector electronics. Again, radiance ratios will be computed for the different gain settings. The data flow diagram for processing gain data is shown in Fig. 13. A time series analysis of these ratios will indicate any changes in the postdetector electronics for each band.

The SeaWiFS calibration table contains correction factors for differences in the reflectance of the two sides of the half-angle mirror (Barnes et al. 1994b). The initial correction factors are based on prelaunch measurements of the mirror. On-orbit correction factors are more easily computed from solar data than from other data types. Changes in the correction factors from their prelaunch values would imply that asymmetric degradation of the mirror has occurred. If such changes occur, the calibration table would

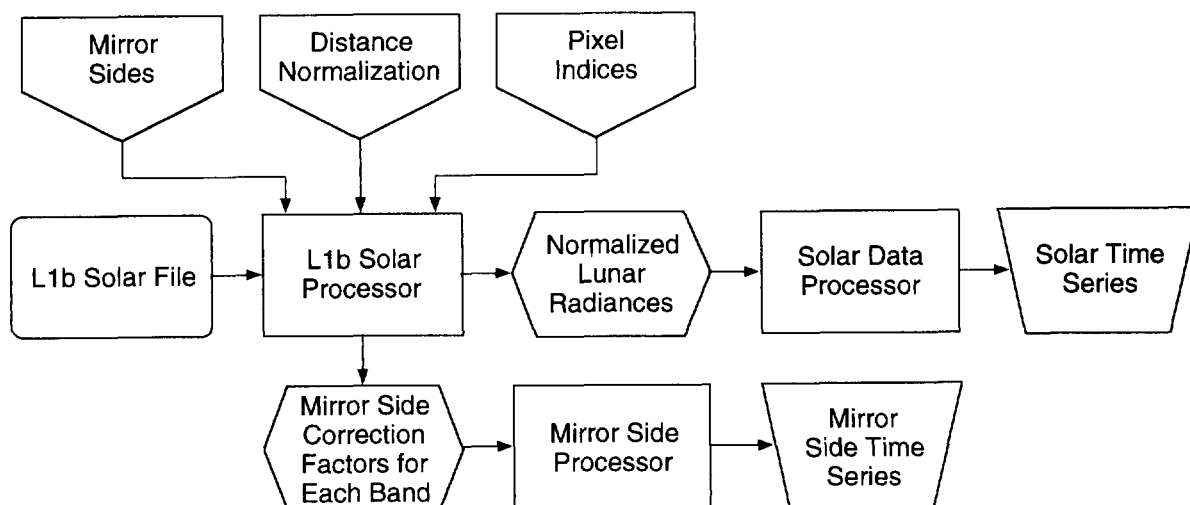


Fig. 7. This flow chart illustrates solar data processing. Solar radiances provide a more frequent calibration reference than is possible with lunar data and are analyzed to check for asymmetric degradation in the half-angle mirror.

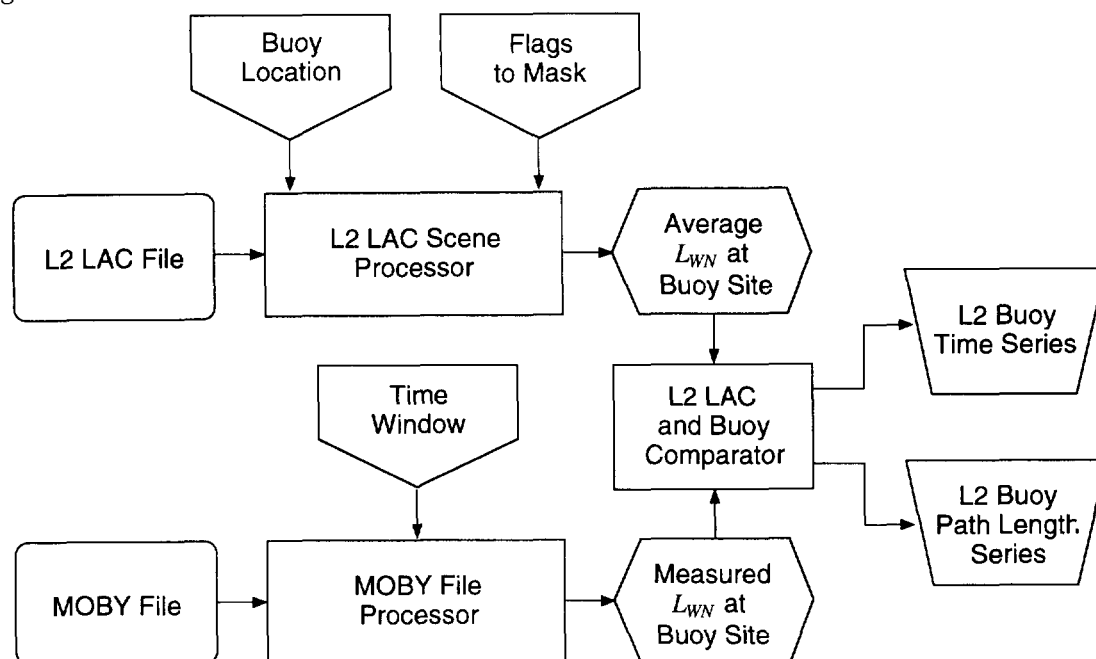


Fig. 8. This flow chart shows L2 LAC and buoy data comparison. Average L2 LAC radiances at the MOBY site are compared with radiances measured by MOBY to monitor the instrument calibration stability.

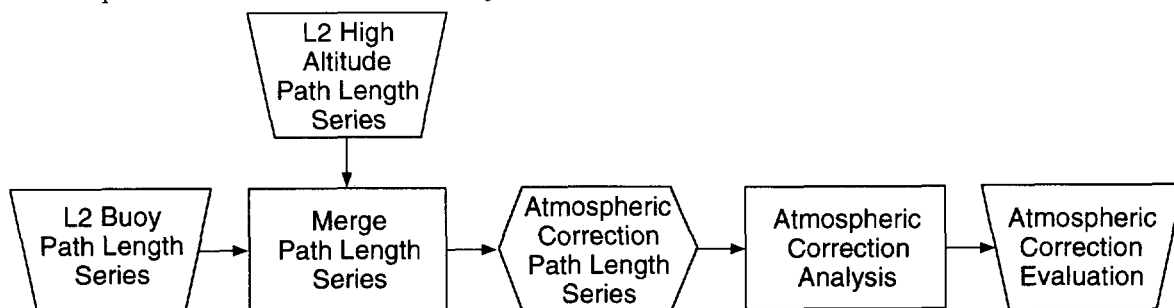


Fig. 9. This flow chart shows the atmospheric correction evaluation. The atmospheric correction algorithm may break down for long optical paths.

SeaWiFS Calibration and Validation Quality Control Procedures

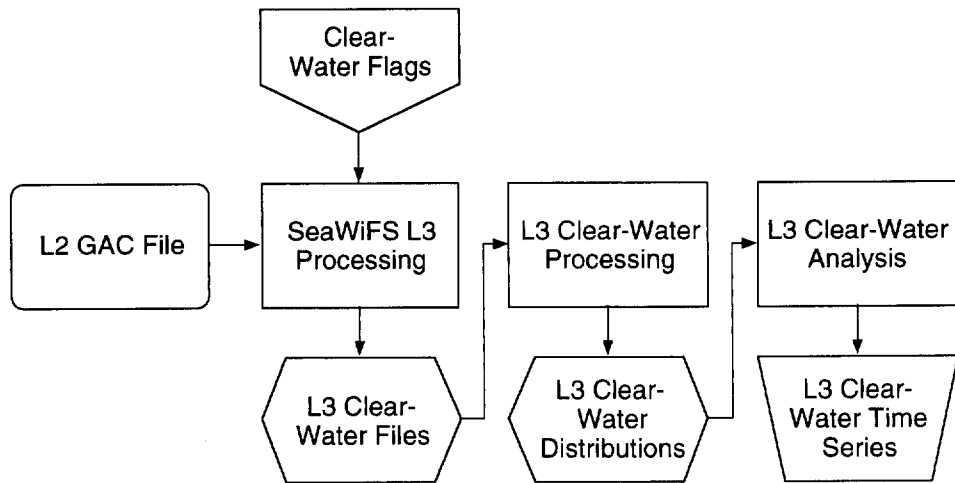


Fig. 10. This flow chart shows clear-water distributions. The distributions of normalized water-leaving radiances for clear water provide a monitor of the instrument calibration stability.

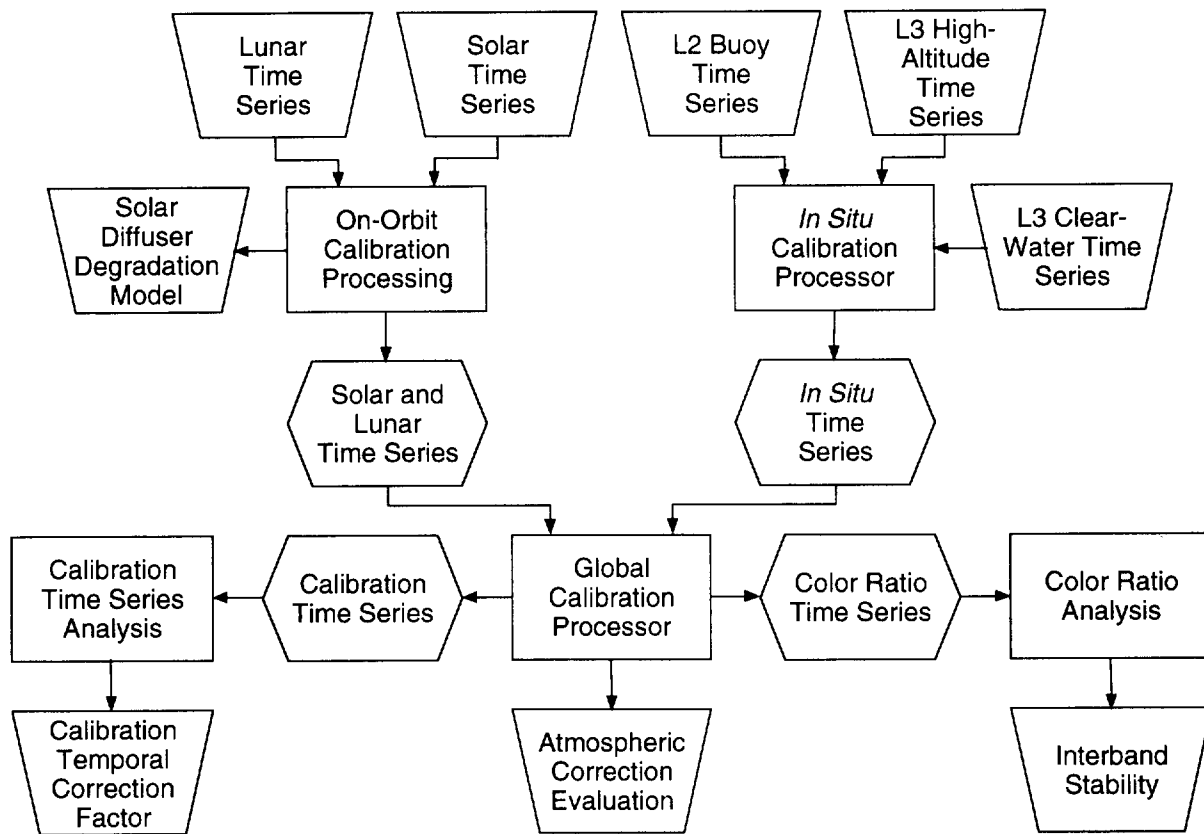


Fig. 11. This flow chart illustrates sensor calibration stability. The solar and lunar time series are merged to form an on-orbit calibration time series. The L2 LAC and MOBY data comparison and the clear-water distribution time series are merged to form an *in situ* calibration time series. The on-orbit and *in situ* time series are merged to form a calibration time series and a color ratio time series. The on-orbit and *in situ* time series are compared to evaluate the atmospheric correction of the L2 data at the vicarious calibration sites.

Table 2. Strategy for organizing calibration verification data files in a directory structure, with a database table pointing to the file locations.

<i>Directory Structure</i>			<i>Data Attributes</i>
SeaWiFS Data Files	Level-1a	Lunar Solar TDI Telemetry	Time tags Lunar phase angle Prediction file name
	Level-1b	Lunar Solar TDI	Time tags Lunar phase angle Prediction file name
	Level-2	LAC HRPT	Time tags Buoy latitude and longitude S/C solar zenith angles MOBY file name
	Level-3	Clear Water	Time tags
Vicarious Data Files	Lunar predictions	Predicted irradiances Model images	Time tags Lunar phase angle L1b file name
	MOBY	MOBY data files	Time tags Buoy latitude and longitude Solar zenith angle L2 file name

HRPT = High Resolution Picture Transmission

S/C = Spacecraft

be updated with the new correction factors. Any symmetric degradation of the half-angle mirror would be absorbed into the calibration temporal correction discussed in the previous section.

Statistical analyses of the spacecraft telemetry data will show any anomalies that occur in the instrument. For a more detailed discussion of this subject, see Firestone et al. (1996), in this volume, and McClain et al. (1995).

2.6.2 Influence of the SAA

A potential source of noise in the SeaWiFS data external to the instrument is the SAA. As the spacecraft passes through the SAA, charged particle impacts on the detectors may increase the noise in the data. While it would be difficult to distinguish this effect in the ocean data, the increased noise should show up as elevated dark counts. The CVE will extract the dark counts from the L1a files and bin the data to an L3 grid. If the SAA adversely affects the SeaWiFS data, the binned dark counts will have elevated values in the area of the SAA. The data flow diagram for processing the dark count data is shown in Fig. 14. Sixteen days of L1a data are binned together to provide complete ground coverage for the analysis.

If the SAA turns out to be a problem for SeaWiFS, a more detailed analysis of the effect will be required to

develop a strategy for dealing with the situation. A possible strategy would be to implement a data quality flag, which would be set when the spacecraft is in the SAA. These flagged data would not be included in the normal SeaWiFS L3 processing. An analysis task would be to determine the effective boundaries of the SAA to use in setting this flag.

2.7 DATA ARCHIVING STRATEGY

One challenge that faces the CVE in performing calibration verification is keeping track of the data files that are used or generated by the verification processing. These data files include SeaWiFS data files in HDF format, vicarious data files (e.g., lunar radiance predictions and MOBY files), and analysis output files (e.g., *daily* output of the analysis routines discussed above), individual time series files produced from the daily output, and merged time series files.

The initial strategy will be to set up a hierarchical directory structure that sorts files by data type. An overview of this structure is shown in Tables 2 and 3. Eventually, a relational database table will be set up that will point to the files in this directory structure. Users will be able to query the database for data sets defined by the attributes listed in Tables 2 and 3.

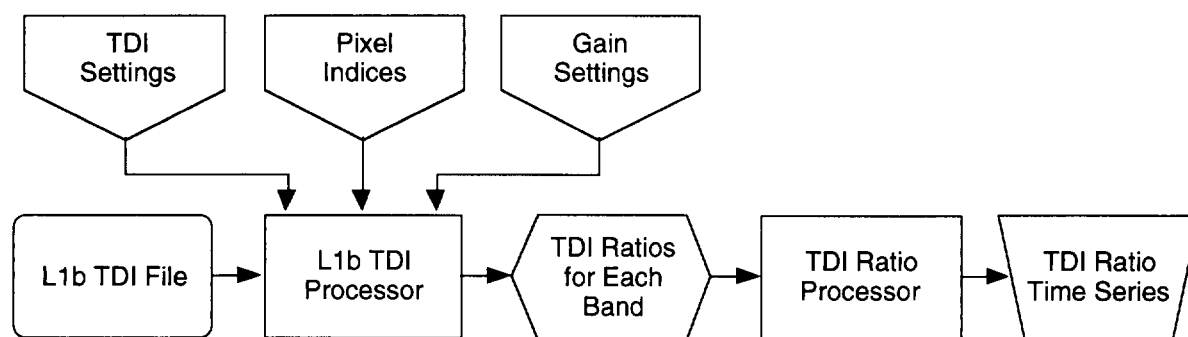


Fig. 12. This is the TDI data processing flow chart. TDI data is analyzed to check for variations in the detectors within each band.

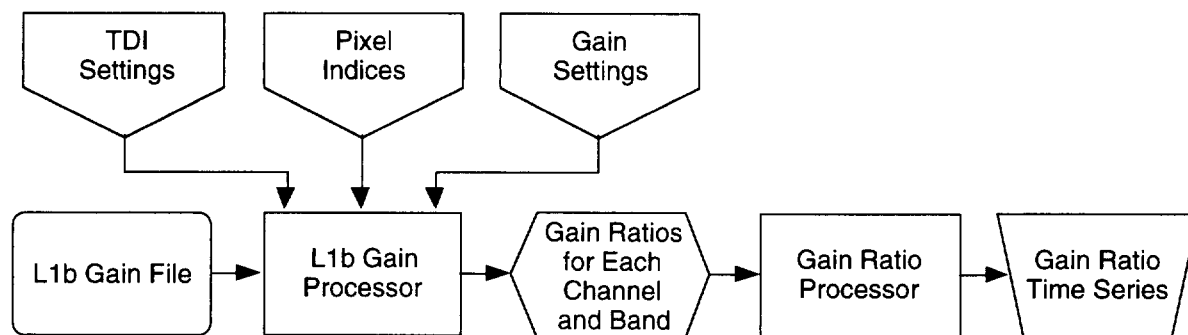


Fig. 13. This is the gain data processing flow chart. Gain data is analyzed to check for variations in the postdetector electronics within each band.

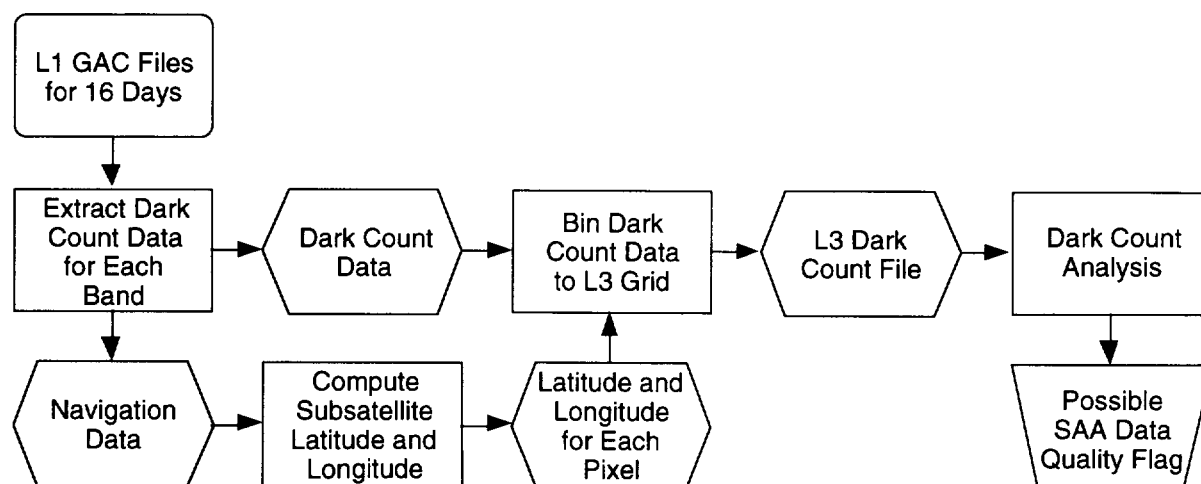


Fig. 14. This is the flow chart for dark count data processing. Dark count data is analyzed to assess the influence of the SAA on the instrument and data.

Table 3. Strategy for organizing calibration verification data files in a directory structure, with a database table pointing to the file locations. The following files (*Analysis Files*) are derived products of those files listed in Table 2.

Directory Structure			Data Attributes
Daily Processing Files	Lunar data	Scaled radiances Normalized radiances	Time tags Lunar phase angle L1b file name Prediction file name
	Solar data	Normalized radiances Gain ratios Mirror side correction factors	Time tags L1b file name
	TDI data	TDI ratios Gain ratios	Time tags L1b file name
	L2 LAC and buoy comparisons	Average L2 LAC radiances Average MOBY radiances Error in L2 LAC radiances	Time tags Buoy position S/C solar zenith angles L2 file name MOBY file name
	L3 clear water distributions	Histograms of normalized water-leaving radiances Histograms of bio-optical parameters Histograms of atmospheric parameters	Time tags L3 file names
	Binned dark count files		Time tags
Individual Time Series	Lunar data	Scaled radiances Predicted radiances Comparison of scaled, predicted radiances Normalized radiances	Time range Phase angle range
	Solar data	Normalized radiances Gain ratios Mirror side correction factors	Time range
	TDI data	TDI ratios Gain ratios	Time range
	L2 LAC and buoy comparisons	Average L2 LAC radiances Average MOBY radiances Error in L2 LAC radiances	Time range Path length range Buoy position
	L3 clear-water distributions	Means of distributions Standard deviations of distributions	Time range
Path Length Series	L2 LAC and buoy comparisons	Average L2 LAC radiances Average MOBY radiances Error in L2 LAC radiances	Time range Path length range Buoy position
Merged Time Series	On-orbit calibration series <i>In situ</i> calibration series Calibration time series		Time range Buoy position

Chapter 3

The Quality Control of SeaWiFS Ancillary Data

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ABSTRACT

Processing SeaWiFS data requires the use of external, i.e., ancillary, data products to derive the set of SeaWiFS standard geophysical (level-2) parameters. Ancillary meteorological data products of total column ozone and surface values of zonal and meridional wind speed, atmospheric pressure, and possibly relative humidity or total precipitable water will be used in the level-2 processing. These ancillary data files are provided by NMC and the TOVS Project; equivalent products may be obtained from other sources. The CVE developed procedures and software to assure the quality of the input products processed using SDPS. Ancillary data files are converted to a SeaWiFS defined specification and stored in HDF files. The HDF data undergo QC procedures using both noninteractive and interactive programs to assess their validity. The data are then used for level-2 processing and are distributed to the research community through the GSFC DAAC. This chapter describes the approaches to QC of SeaWiFS ancillary files through software used by the SeaWiFS Project.

3.1 INTRODUCTION

The processing of SeaWiFS data from level-1a (uncalibrated radiances) to level-2 (derived products) requires five near-real time (NRT) ancillary fields (Fig. 15):

1. Total ozone,
2. Surface values of zonal (east-west) wind speed,
3. Surface values of meridional (north-south) wind speed,
4. Atmospheric pressure, and
5. Relative humidity;

which are incorporated into the atmospheric correction algorithm (relative humidity is not currently used). These data products are converted to HDF files, according to the specifications of the SeaWiFS Project (Darzi et al. 1995). All verified ancillary data products are made available to researchers through the GSFC DAAC.

To assure the validity of the ancillary data products, two types of programs have been developed. The first is a noninteractive or *automatic* program used for rapid, computer controlled statistical checking of the data and the second is a user controlled interactive program that allows an operator to view and modify data files. Both of these

programs are used by the CVE of the SeaWiFS Project (McClain et al. 1992) and are explained in further detail below.

3.2 NONINTERACTIVE QC

Noninteractive QC is designed to produce rapid statistical evaluations of NRT SeaWiFS ancillary data files without the need for repetitive and time consuming operator interaction. The two programs used for this purpose are METQC for meteorological data and O3QC, for ozone data. Two programs are used because of the different formats of the respective data and the difference in data availability and processing times. Both programs are written in the C language for use on the Project's Silicon Graphics, Inc. (SGI) UNIX workstations in the SDPS. METQC and O3QC are executed via a UNIX shell script, which is started by a call from the SDPS database whenever newly generated products in need of QC are created. When completed, the SDPS database is updated to reflect the result of the QC operation. Depending on the results from the noninteractive QC, the file is declared either ready for use in SeaWiFS level-2 processing, or it is declared as requiring operator intervention to repair or replace the ancillary data.

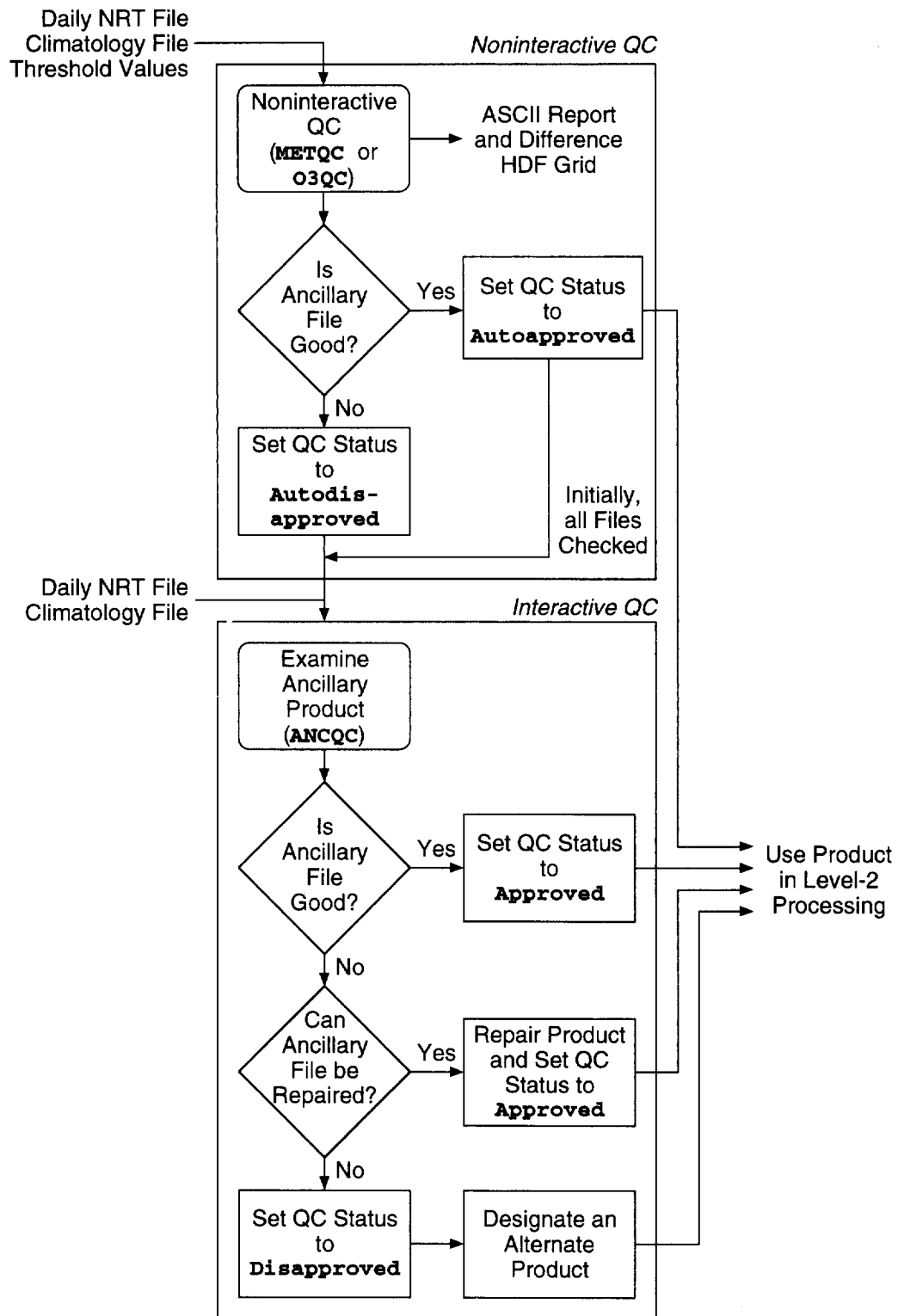


Fig. 15. This figure shows an overview of the ancillary data products and processing.

The METQC or O3QC programs, depending on the input data going through the QC process, compare an NRT HDF ancillary file to the corresponding month in a climatology (CLM) file, which was developed using multiyear averaging of the ancillary parameters (Schieber and Firestone 1993, and Firestone and Schieber 1994). The processing steps for using the METQC or O3QC programs are as follows (Fig. 16):

1. An automatic process on the SDPS starts a UNIX *shell* script that runs the METQC or O3QC with arguments for input and output file, directory, and QC thresholds.
2. The shell script executes METQC or O3QC depending on the ancillary data being processed.
3. The METQC or O3QC programs open and read the NRT products and the corresponding monthly data from the CLM file into memory and performs a statistical comparison between the two data sets.
4. An ASCII report is generated (Fig. 17) that shows the number and percent of points in the NRT file which fall within one, two, or three standard deviations ($1-3\sigma$) of the corresponding point in the CLM file (based on latitude and longitude locations). Other values, such as the number of missing points in the NRT or CLM file, are also reported. This report is stored on the processing computer and can be electronically mailed (e-mailed) to the processing administrator for evaluation.
5. An HDF file is generated that contains the number of standard deviations by which the NRT and CLM data varies at each point in the compared grids. Optionally, this output can be a simple numerical difference between the two grids. This output QC file can be utilized in the interactive QC (IQC) program to show the variation of individual NRT points relative to the climatology and also serves as a data record.
6. The calculated percentage of points falling within $1-3\sigma$ are checked against the three corresponding thresholds provided to the program. If the percentage of points calculated in the program are lower than any of the supplied threshold limits, the program will return a *failed threshold* flag to the calling shell script.
7. The program returns control to the calling script. The SDPS database is informed that there is a new file ready for the IQC program by setting the QC status code to a value of **Autoapproved**. If the program's return flag indicates the NRT data file has failed the comparison test, the script informs the database by setting the QC threshold flag to a value of **Autodisapproved**. Products with the **Autodisapproved** value require examination and possible modification using the IQC program prior to their use in the level-2 SeaWiFS image product generation program.

3.3 Interactive QC

The ancillary QC program ANCQC provides a mechanism for interactive viewing, manipulation, and modification of the values in an ancillary HDF data file. The ANCQC program is written in IDL which provides a comprehensive package for image display, image processing, and statistical analysis. In addition, IDL provides a high-level programming language and tools for building GUIs. Finally, IDL provides support for HDF files which are used by the Project.

The ANCQC program performs a number of interactive functions on ancillary data. The primary functions of the program are to view ancillary data files and to allow for the substitution of data outliers with data from other data files (temporal interpolation), climatology files, or by spatial interpolation. Missing or erroneous data can be replaced and documented using the tools in the ANCQC program. The user also has the ability to define a region of interest (ROI) on an image and modify only the data within or outside that region.

Numerous other tools of the ANCQC program, used for investigation of the data, are available. These are described in greater detail in the on-line help for the program. A brief listing of ANCQC tools provided includes:

- a) Clear and restore an image;
- b) Change the color table and color palette;
- c) Place a land mask over the image;
- d) Show a bar plot of data scaling;
- e) Animate a 12-month CLM file or a selected set of NRT files;
- f) Show header data (metadata) for a selected file;
- g) Create an image of wind speeds from zonal and meridional data grids;
- h) Show a shaded 3-D surface plot of data;
- i) Plot latitude and longitude grids over data;
- j) Show modified points in a data grid;
- k) Annotate an image with text and figures;
- l) Contour data;
- m) Show a spreadsheet of the data; and
- n) Zoom in on the entire image or on a selected region.

ANCQC interacts with the SDPS database to determine which files will undergo QC and displays these files in its file selection window. The program also interacts with the SDPS database to update a QC status flag after a file has been through QC and possibly modified.

The processing steps for ANCQC are as follows:

1. The user starts the ANCQC IDL program.
2. The ANCQC program queries the database for any files marked with the **Autodisapproved** status on startup and displays a list of filenames for selection.

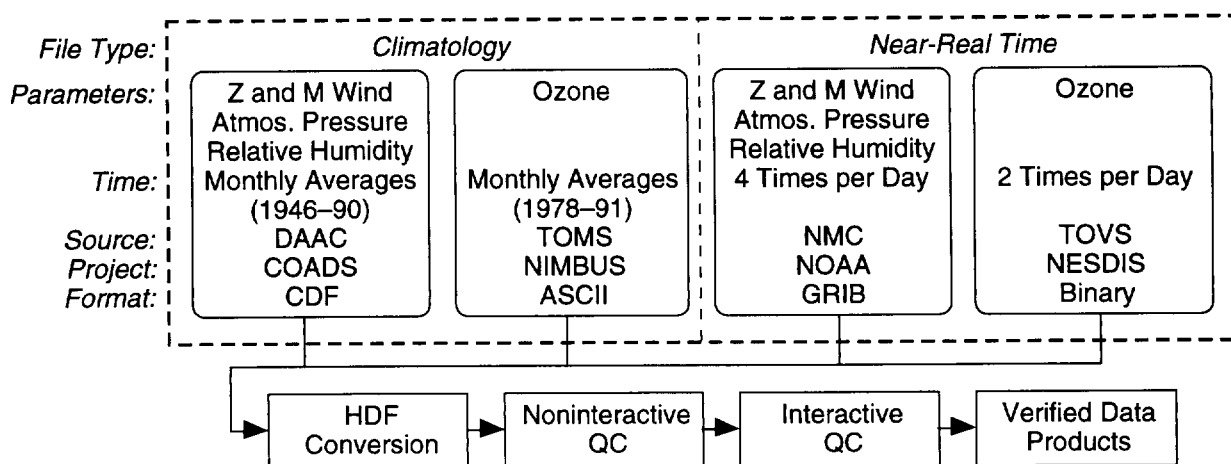


Fig. 16. This figure shows noninteractive and interactive ancillary QC processing with file status interactions to the database.

Results of comparison of real-time and climatological files:

/usr/seadas/data/S19952741827608.TOVS.OZONE

/usr/seadas/data/S19891991.TOMS.OZONE

Month: October Parameter: Ozone

Total # values - missings: 44269

Total # points/percentage < -1 STD: 18236 (41.19 percent)

Total # points/percentage +/- 1 STD: 24441 (55.21 percent)

Total # points/percentage > 1 STD: 1592 (3.60 percent)

Total # points/percentage < -2 STD: 6058 (13.68 percent)

Total # points/percentage +/- 2 STD: 38027 (85.90 percent)

Total # points/percentage > 2 STD: 184 (0.42 percent)

Total # points/percentage < -3 STD: 1327 (3.00 percent)

Total # points/percentage +/- 3 STD: 42899 (96.91 percent)

Total # points/percentage > 3 STD: 43 (0.10 percent)

Total # missing values: 7571

Total # missing real-time: 7571

Fig. 17. This is the ASCII report from the 03QC program showing the determined standard deviation percentages for comparing daily and climatological files.

Initially in SeaWiFS processing, even files marked **Autoapproved** will appear for visual checks.

3. The user selects an NRT product to go through the QC process.
4. The **ANCQC** program displays the data parameter(s) for the product selected, and also displays the data from the corresponding climatological month in an adjoining display window. For total column ozone data, only one NRT and one CLM grid are displayed. For meteorological data, the four meteorological data parameters are displayed along with their four corresponding CLM images.
5. The user views the NRT parameters and can modify data points using any of several possible modification methods provided by the **ANCEDIT** routine.
6. The modified NRT file is saved as a new HDF file.

Modified data files are documented internally by using HDF header information (metadata) and by modifying QC grids associated in a point-to-point fashion with the actual data grids.

7. The **SDPS** database is informed by the user of the new status of the NRT files. The new status will be either: a) **Approved**, b) **Approved (with modified points)**, or c) **Disapproved**.

Once the file's status is modified, is it eliminated from the **Files to QC** list on the **ANCQC** user interface.

The ancillary data processing sequence is run daily on four 6-hour meteorological and two 12-hour ozone ancillary data files. Records are stored in the metadata of the NRT files to log modifications and operator comments. In addition, generated reports are stored on the **CALVAL** computer to log processing times and to compare results.

Chapter 4

SeaWiFS Data Quality Control Software

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ABSTRACT

This chapter presents the procedures and software employed to monitor and control the quality of the geophysical data from the SeaWiFS instrument aboard the SeaStar satellite. The QC programs consist of a set of automated programs which verify that the data conforms to broad statistical guidelines, and interactive programs that allow for more in depth investigation of problems, as well as a final level of approval for the data. The QC programs are applied to the data in all three stages of processing: level-1a, level-2, and level-3. The procedures for the efficient use of these programs are also discussed.

4.1 SOFTWARE OVERVIEW

The SeaWiFS data QC software is used by the CVE to assure that only high quality SeaWiFS products are archived in the GSFC DAAC. This goal is achieved by applying interactive and automated checking procedures to the data as they pass through all three levels of processing: level-1a, -2, and -3. The checking varies depending upon the data type and processing level and is described in detail in the following sections.

The QC programs are designed to achieve three main objectives:

- 1) Locate unexpected problems in the data coming from the satellite;
- 2) Locate data problems created by the processing software; and
- 3) Allow the testing of alternate scientific algorithms for the processing of data—this only applies to the level-2 data.

The remainder of this section gives an overall description of the QC data flow. Sections 4.2, 4.3, and 4.4 describe the purpose, features, input, and output of the level-1a, -2, and -3 QC programs in more detail. Each section includes a description of how to run the QC program, along with diagrams of the important interfaces and descriptions of their features. Section 4.5 describes the automatic level-1a, -2, and -3 QC programs. Section 4.6 presents a highly detailed discussion of the data flow and the QC interactions.

Figure 18 shows the QC processing flow in relation to the level-1a, -2, and -3 processing by the SDPS. The

SDPS first processes the raw SeaWiFS data into detector counts and navigation information called level-1a (L1a). The next processing step calibrates the counts to generate radiances, corrects the radiances for atmospheric absorption, and determines bio-optical quantities from the corrected radiances to produce a level-2 product (L2). Finally, the data are binned from the line, pixel coordinate system into a regular grid. This is accomplished on individual level-2 products to create level-3 space binned products (L3S) which are then accumulated on a daily basis into a level-3 time binned product (L3T). Additional binning is done to produce weekly, monthly, and yearly binned products. Several segments of SeaWiFS data are processed in a day from the raw form to L3S products; the processing steps for each segment are called a stream.

In addition to this processing, browse images are created from the level-1a and -2 products. The L3T product is processed to create a standard mapped image of certain geophysical parameters, and a browse product of chlorophyll *a* is generated from the chlorophyll *a* standard mapped image. These processing steps are not shown in Fig. 18.

When SDPS completes a product, it is checked with the automatic level-1a, -2, and -3 QC programs, which run tests on the products to check their integrity and data quality within established thresholds. A status report is then generated if any problem is detected in any of the products.

When the L3T product is created and checked, the interactive portion of the QC is started by members of the

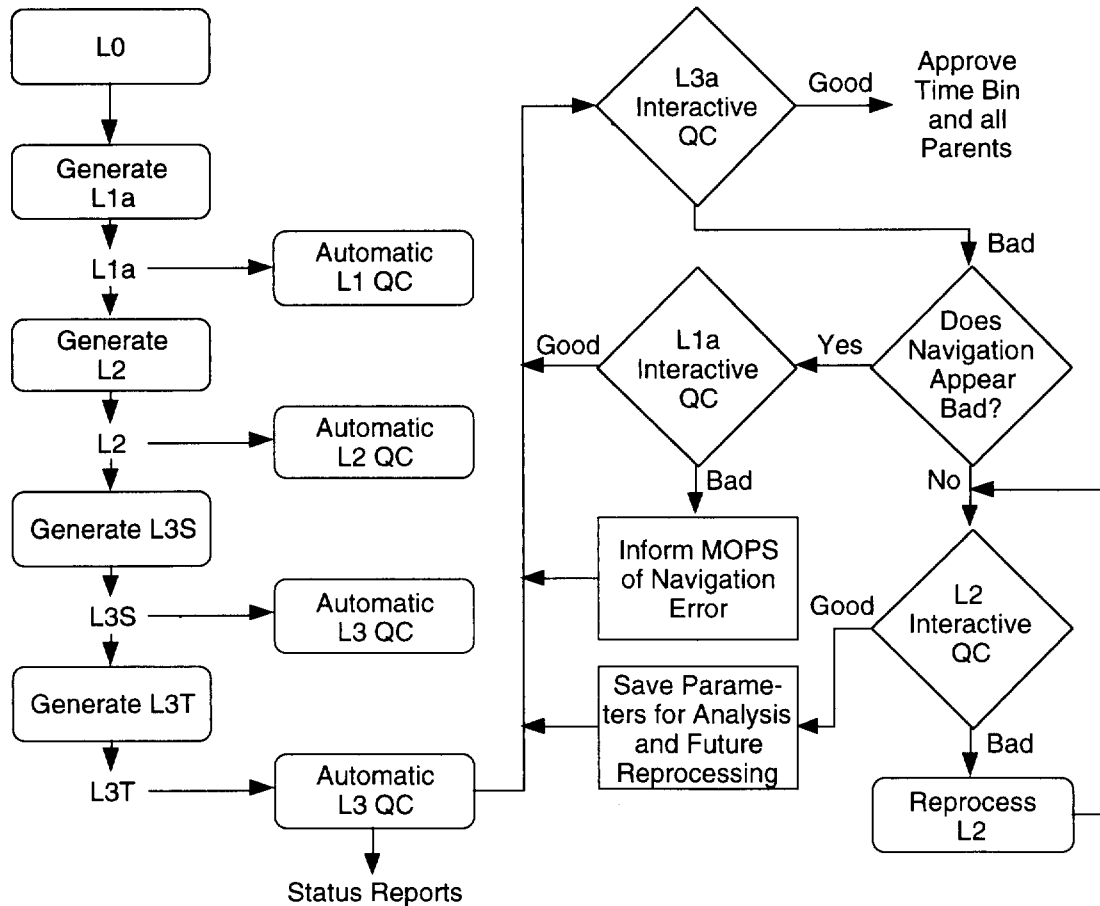


Fig. 18. The layout of the level-1a, -2, and -3 GAC processing and quality control is shown here.

CVE. First, any QC status reports are examined and the associated product is checked. Then, the level-3 IQC program is run on the L3T product. An examination of the L3T product gives an indication of the quality of most of the level-1a, -2, and -3 products which were created during the day. The advantage of checking the L3T file is that only one product needs to be checked instead of the approximately 30 level-1a and -2 products that make up the L3T. If a problem is detected in the L3T, either the level-1a or level-2 IQC can be run on the parent product. The level-3 IQC program lists the parent products for any point in the time binned product and can invoke the level-1a or -2 IQC program on that product directly, making it easy to examine the product in more detail.

Each IQC program checks certain aspects of the data quality, as indicated in Fig. 18. The level-1a QC is designed to detect and measure navigation errors by determining coastline offsets between the image and the coastline drawn using the navigation information. These problems are then forwarded to the Mission Operations element for study and correction so that global reprocessing can apply the correction later. The level-2 QC is designed to detect problems in the radiance calibration, the atmospheric

correction, flag and mask thresholds, and the derivation of bio-optical parameters (Gordon and Wang 1994 and McClain et al. 1995).

The level-2 QC can aid in establishing improved performance of the level-1a to level-2 processing by noting the results of reprocessing a subarea of the data from level-1a to level-2 with different input processing parameters or algorithms.

The level-3 QC verifies that the binning of the data is performed correctly and detects problems in the level-1a and -2 processing. The parent products can be identified and the contributions to an individual level-2 bin can be assessed. (Section 4.6 presents a more detailed discussion of the QC procedures followed by SDPS and CVE during the generation of operational products.)

4.2 LEVEL-1A QC PROGRAM

The main purpose of the level-1a QC program is to detect and measure navigation errors in the GAC and LAC products. It also allows for qualitative and quantitative checking of the image quality, as well as monitoring the sensor health.

4.2.1 Summary of Features

The level-1a QC program has the following features:

- 1) Simultaneous display of all eight bands of level-1a data (at reduced resolution);
- 2) Full resolution display of a selected band of data;
- 3) Graphic display of the coastline over the image data;
- 4) Display of any or all the engineering flags and instrument tilt states;
- 5) Display of metrics and other metadata;
- 6) Display of information at a point including location (latitude, longitude, line, and pixel) and data values in all eight bands;
- 7) Recording of the observed navigation offsets and saving them to a file; and
- 8) Database connections to allow the selection of a product and the approval or disapproval of the data based on its quality.

4.2.2 Program Requirements

The level-1a QC processing requires two input files to operate: the level-1a product that will go through the QC process, and a file containing the coastline overlay. The default coastline overlay file has a resolution of 12 km but higher resolution files are also available.

The level-1a QC program has the following hardware and software requirements:

- a) It must run on an SGI workstation with the 24-bit graphics option and the GL graphics library;
- b) Although required only for software updates, the User Interface Management/X-Windows (UIM/X) GUI builder should be present; and
- c) In order to use the Sybase database, the level-1a QC program must have access to the Sybase client software. This can either be the CALVAL computer, which has Sybase, or any computer that can access the client software via a network file services (nfs) mount.

The level-1a QC program is started with the command `QC11int`. As an option, this can be followed by the file name of the level-1 product to check. Upon startup, the level-1a QC program displays the **Main** interface (Fig. 19). Other than product queries, all controls for the level-1a QC program are contained in this interface. The elements in the interface are described below in the order that they typically would be used.

The level-1a input product is specified first. It can be specified at startup or it can be specified in the program by querying the database from the **File** pull-down menu. Either way, the selected level-1a product is immediately loaded and displayed.

The level-1a QC program interface contains a large image area which displays a full-resolution image of SeaWiFS

band 1 after the level-1a product is selected. Scroll bars on the sides control the portion of the image that is viewed at any time. Nine smaller displays show reduced resolution views of all the data in each of the eight SeaWiFS bands and the coastline overlay itself. The buttons below each band can be selected to display that band at full resolution in the large image area.

Quantitative information about the level-1a data can be displayed for any image point selected by the cursor. The geographic location, the scan line, and scan element and the counts in all eight bands are displayed. This information can be updated each time the cursor moves or just when the mouse button is pressed.

Any of the engineering or tilt state flags may be overlaid on top of the full resolution image to determine any correlations with data anomalies. The color of the flags can be controlled and they may be easily toggled on and off.

Navigation offsets can be selected and recorded by locating their corresponding points in the coastline seen in the level-1a data and the graphic overlay of the coastline. These locations will be displayed as markers on the screen and their line and pixel location will also be displayed. Pairs of coastline and map points can be collected to record the observed navigation offsets. The differences between these pairs can then be computed and displayed in a registered targets list. The navigation offset information is output to a file by specifying the **Save Registered Points** option in the **File** pull-down menu.

When the data quality has been determined, the QC status of the product can be updated using one of the options in the **Approve/Disapprove** pull-down menu. (Section 4.6 has a detailed discussion of the QC status codes.) Although both approved and disapproved products are processed and archived, the **Disapproved** status is important because it marks the product as having a problem that may have an impact on the level-2 and other downstream products.

When the processing for this product is complete, the **Quit** option can be invoked from the **File** pull-down menu.

4.2.4 Future Enhancements

The level-1a QC program satisfies all the basic requirements and is ready for operational use. As time permits, the following features will be added: a) an ability to place the cursor at a specified latitude and longitude; and b) an improved interface for describing the engineering and tilt flags to be shown. The latter feature includes a separate interface for specifying the flags and a descriptive text for the meaning of each flag.

4.3 LEVEL-2 QC PROGRAM

The main purpose of the level-2 QC program is to make sure the level-1a to level-2 processing is working correctly. This includes:

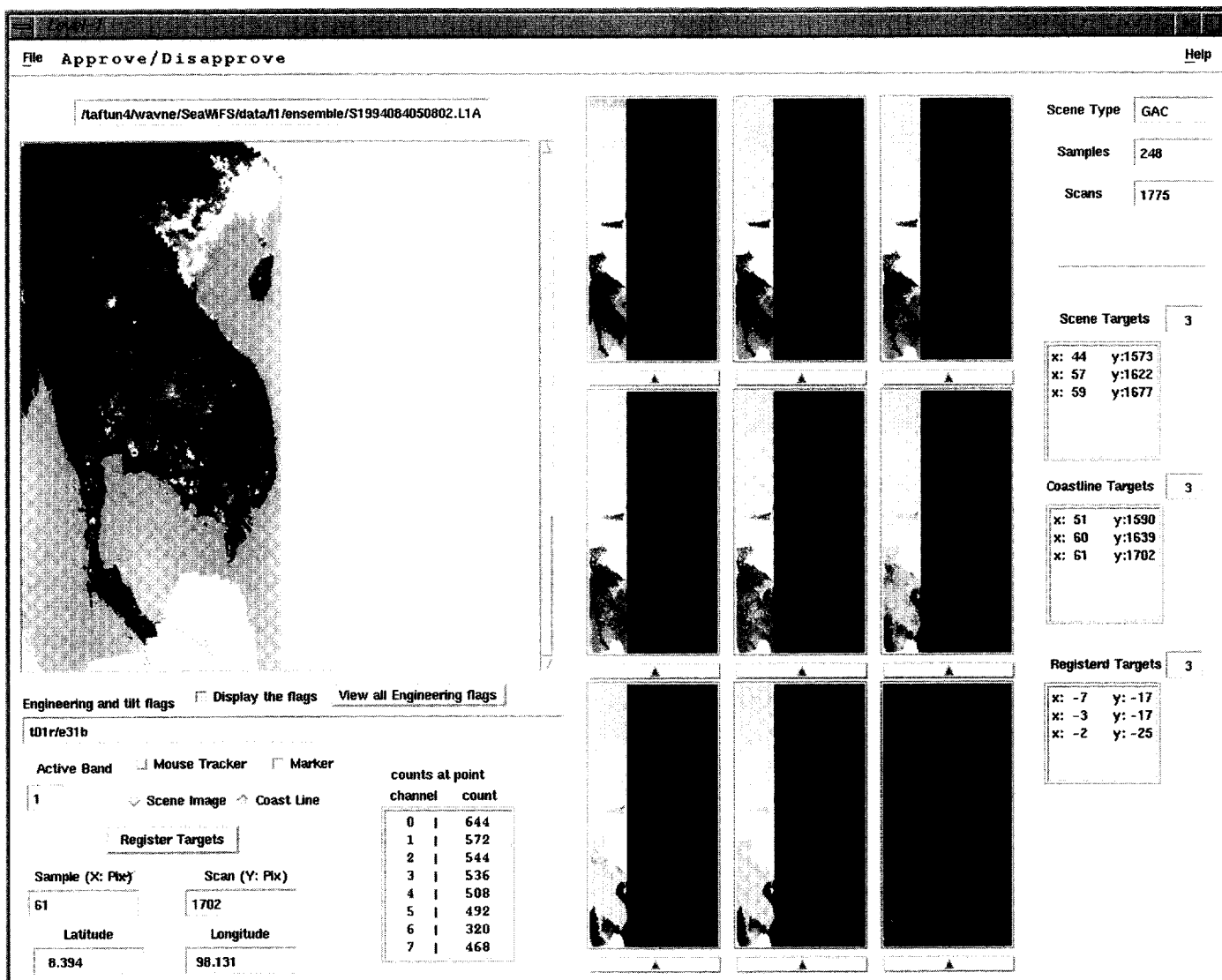


Fig. 19. A picture of the level-1a QC Main interface is shown above.

- i. Checking the general quality of the resulting products;
- ii. Examining the flags and masks to insure that the exclusion thresholds are not too restrictive or too lax; and
- iii. Testing new processing algorithms in order to observe their performance in relation to the operational algorithm. This operation will also be carried out in a more thorough manner in the data match-up programs (Yeh et al. 1996).

The level-2 QC program may also be used to examine problems in the level-1a data processing.

4.3.1 Summary of Features

The level-2 QC program has the following features:

1. Display any combination of the following in separate windows: a) Any level-2 parameter from the level-2 product; b) Any band of the parent level-1a product; and c) Any QC parameter from the associated level-2 quality control (level-2 QC) product.
2. Display the selected level-2 processing flags as an overlay with selectable color.
3. Display the selected engineering flags and/or instrument tilt states as an overlay with selectable colors.
4. Display a zoomed portion of the image.
5. The cursor controls the area of interest.
6. The reprocessing function allows the level-2 processing of a subarea of the data with different input parameter values or algorithms so that comparisons of the results can be made. Data and/or flags can be selected for this reprocessing.
7. The Sybase database connection allows the selection of a product and to approve or disapprove the

product (and its level-1a parent) based on its quality.

4.3.2 Program Requirements

The level-2 QC program can use level-1a, level-2 QC, and level-2 products during the QC process, although primarily, it uses the level-2 product. The level-1a parent product is necessary if reprocessing will be done.

The level-2 QC program has the following hardware and software requirements:

- It can run on either an SGI workstation that has 8-bit color or an X-terminal with 8-bit color.
- The host computer must have the IDL software and an IDL license.
- In order to use the Sybase database, the QC program must have access to the Sybase client software. This can be either the calval computer, which has Sybase, or any computer which can access the client software via an nfs mount.

4.3.3 Program Operation

The level-2 QC program is started within IDL. To start the program, enter the command: `QC12int`. This command can be followed optionally by the file name of the level-2 product to check.

4.3.3.1 General Interface Description

The level-2 QC program contains several interface windows (interfaces) which provide the specified functionality. Four of the most important interfaces, which examine the level-2 data and test the effects of modified data reprocessing, are described here.

Upon startup, the level-2 QC program displays the **L2CHK** interface (Fig. 20). The **L2CHK** interface can call many other interface panels for changing input parameters for reprocessing and viewing data. The primary interface panel called to view the data in image form is the **Level-2 Image and Flags** interface (Fig. 21). Simultaneously, a level-1a band and a level-2 QC parameter can be displayed in separate interfaces. While in the **Level-2 Image and Flags** interface, reprocessing of a selected section of the data with modified input can be started by invoking the **Level-2 Reprocess Set Up and Information** interface (Fig. 22) to modify the input and the **Level-2 Reprocess Display Window** interface (Fig. 23) to view the results.

The following sections describe each of the four interfaces in more detail.

4.3.3.2 The L2CHK Interface

The **L2CHK** interface (Fig. 20) contains many controls for the selection of the level-2 data to be displayed. These

controls allow for the selection of any level-2 geophysical parameter, level-2 QC parameter, or any band from the level-1a parent product. Data quality, engineering, and tilt flags can also be selected for display. The elements in the interface are described below in the order that they typically would be used.

The level-2 product is specified first. It can be specified at startup or it can be specified in the program by using the **Database Query** button. Either way, a selectable set of level-2 parameters and navigation values are read so that they are quickly available for display.

Once the product is specified, the desired band or parameter, and flag data are chosen for display as an image. The image area and data subsampling may be chosen to control the amount of data that can be viewed in the scrollable image area. Three pull-down menus are provided to permit the selection of the level-1a band, the level-2 parameter, and the level-2 QC parameter to be displayed in separate display interfaces. Controls are initially set to produce an image of only the level-2 parameter, but these can be modified to also produce the level-1a and -2 QC images at the same time. The level-2 QC flags generated during the level-1 to level-2 processing, can be selected for display via a set of 16 toggle buttons. The four instrument tilt states and the engineering flags can also be selected in this way.

An image of the selected band and/or parameter can be generated in a number of ways through the use of the display action buttons. These buttons are also used to update the **Image and Flags** interface displayed with different image or flag data. The buttons allow the display of only the parameter, only the flags, or both the parameter and a graphic overlay of flags. The image data is displayed or updated in the **Level-2 Image and Flags** interface, which is described in the next section.

A number of other interfaces containing controls may also be invoked from this interface. Among the functions that can be performed are:

- 1) Animate a series of level-2 parameter and flag combinations;
- 2) Zoom in on an area of the image data;
- 3) Display a spreadsheet of the level-2 parameter values;
- 4) Adjust the color assigned to the flags; and
- 5) Adjust the colors applied to the image data.

When the data quality has been determined, the product's QC status is updated by pressing either the **Approve** button to approve the level-2 product or the **Disapprove** button to disapprove the level-2 product. Section 4.6 discusses the details of the QC status values applied.

When processing for this product is complete, the **Quit** button can be pressed to exit the level-2 QC program and close all the interfaces.

Input L2 file: Database Query

Dimension (pixel/line): 248 / 3595

Output display options:

Scroll Window Size (X/Y):

Pixel Sample Rate: Line Sample Rate:

L1 Band: L2QC Prod: L2 Prod:

Display Action Buttons: Apply to : ☒ L2 data ☐ L1 data ☐ L2QC data

One Flag: Engin. quality: (0 for all)

Many Flags: (1,2,3,4,5,6,7,8)

☐ 1. failure of atmos. corr. algo. ☐ 12. turbid, case-2 water

☐ 2. land ☐ 13. large solar zenith angle

☐ 3. missing ancillary data ☐ 14. high aerosol concentration

☐ 4. Sun glint ☐ 15. low water-leaving rad. at 550nm

☐ 5. high total radiance ☐ 16. chlorophyll algorithm failure

☐ 6. large spacecraft zenith angle ☐ 17. tilt state 0

☐ 7. shallow water ☐ 18. tilt state 1

☐ 8. negative water-leaving rad. ☐ 19. tilt state 2

☐ 9. stray light ☐ 20. tilt state 3

☐ 10. cloud and ice ☐ 21. engineering quality

☐ 11. coccolithophores

Database Disposition of File

Fig. 20. This is the level-2 main interface: L2CHK.

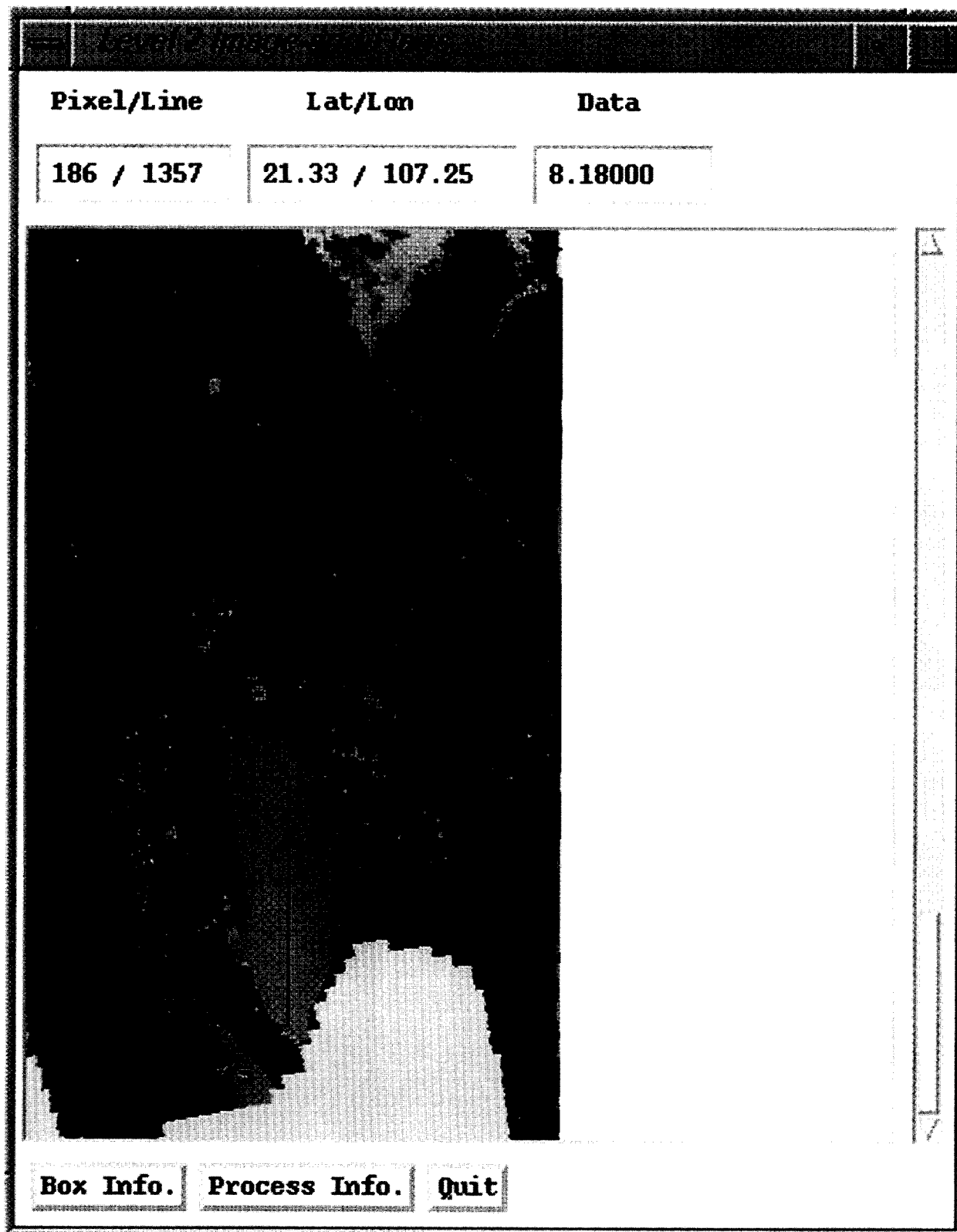


Fig. 21. This is the Level-2 Image and Flags interface.

Reprocess option: ☒ L2 products ☐ Flags

Input L1 file

Flags/Masks threshold: **Original** **New**

Sum glint	0.005	0.005
High tau(865)	0.9	0.9
Spacecraft zenith angle	45.0	45.0
Solar zenith angle	70.0	70.0
Turbid case 2	3.42	3.42
Coccolithophore 1	1.1	1.1

Original **New**

NMC1 file	<input type="text"/>	<input type="text"/>
NMC2 file	<input type="text"/>	<input type="text"/>
NMC3 file	<input type="text"/>	<input type="text"/>
TOVS1 file	<input type="text"/>	<input type="text"/>
TOVS2 file	<input type="text"/>	<input type="text"/>
TOVS3 file	<input type="text"/>	<input type="text"/>

Quit **Go**

Fig. 22. This is the Level-2 Reprocess Set Up and Information interface.

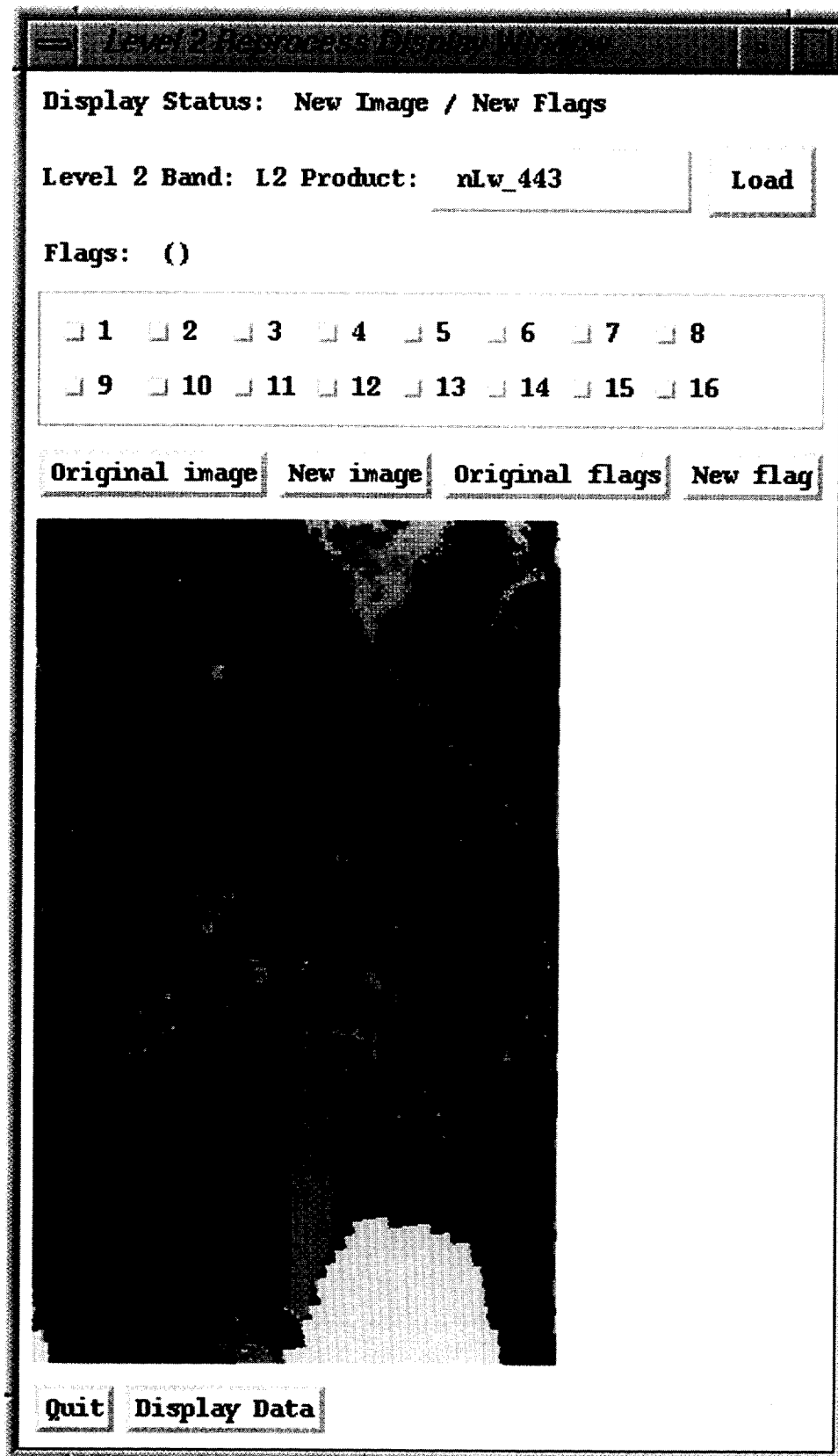


Fig. 23. This is the Level-2 Reprocess Display Window interface.

4.3.3.3 Level-2 Image and Flags Interface

The **Level-2 Image and Flags** interface (Fig. 21) is invoked by the L2CHK main interface to display the selected level-2 parameter and flags in image form. A subarea may also be chosen from the image for performing level-2 reprocessing.

The image area of this interface shows the level-2 parameter in either grey shades or in false color. Superimposed upon this image are flag information or instrument tilt states that were requested in the L2CHK interface. The parameter value at the location of the cursor, as well as geographic, line, and pixel location are displayed in text areas above the image.

To perform reprocessing of the level-1a data to level-2, a reprocessing region is first specified on the image by dragging an adjustable box over the desired portion of the image. The position and size of the region is changed with the left and right mouse buttons. The location and size of the box can be viewed by pressing the **Box Info** button. Once the desired region is chosen, the reprocessing input is specified by pressing the **Process Info** button to invoke the **Level-2 Reprocess Set Up and Information** interface, described in the next section.

The **Quit** button is pressed to close the **Level-2 Image and Flags** interface.

4.3.3.4 Level-2 Reprocess Set-Up Interface

The **Level-2 Reprocess Set Up and Information** interface (Fig. 22) is used to specify the input parameters to use during the reprocessing of a region of the level-1a product to the level-2 form. The **Reprocess Option** buttons allow the reprocessing of either the data, the flags, or both. If an alternate level-1a product is to be reprocessed, it can be specified here. The controls that can be changed for reprocessing come in the form of threshold values and ancillary data files. Two lists are presented showing the original input values that were used to create the level-2 product and an editable list of new input to use during reprocessing.

Once the new reprocessing input values are chosen, the **Go** button is pressed to begin the reprocessing and to display the resulting product in the **Level-2 Reprocess Display Window** interface, described in the next section. The list of new thresholds and files is saved so that they may be used for future reprocessing of the entire product.

The **Quit** button is pressed to close the **Level-2 Reprocess Set Up and Information** interface. No reprocessing is performed.

4.3.3.5 Level-2 Reprocess Display Interface

The **Level-2 Reprocess Display Window** interface (Fig. 23) is used to display and compare the old and newly reprocessed level-2 parameters and flags.

An image area displays a chosen parameter and flags of the original level-2 data. Inside the region, where reprocessing was specified, either the original or reprocessed (new) data or flags may be viewed to determine the effect of the reprocessing to the region in the context of the whole data pass.

When examination of the reprocessed data is complete, the **Quit** button is pressed to close the **Level-2 Reprocess Display Window** interface.

4.3.4 Future Enhancements

The level-2 QC program is fully operational. The reprocessing portion will be updated in the future with new level-2 processing algorithms as they become available.

4.4 LEVEL-3 QC PROGRAM

The main purpose of the level-3 QC program is to monitor the binning procedure used to place the level-2 data values into the level-3 product (Campbell et al. 1995). Any problems in the data or in the level-1a and -2 processing can also be observed here. Capabilities include checking the general quality of the data and its navigation, displaying the data for any bin, and determining the parent level-2 products from which the data originates.

4.4.1 Summary of Features

The level-3 QC program has the following features:

- 1) Displays any of the 12 parameters in the product statistically (mean, median, etc.), in addition to displaying other statistical data;
- 2) Displays the coastline and geographic grid as a graphic overlay;
- 3) Displays the data in any of 12 standard map projections;
- 4) Displays the boundaries, as a graphic overlay, of the satellite passes that make up the product;
- 5) Controls the way the image, grid, and continent data are displayed in the display window;
- 6) Provides the capability of loading a look-up table (LUT);
- 7) Navigates a point on the screen with the ability to place the cursor at a specific point;
- 8) Determines the level-2 parents of a data point;
- 9) Displaying all the information at a point in the data; and
- 10) Having database connections to allow the selection of a product and the approval or disapproval of the data based on its quality (the approval condition is automatically applied to the parent level-1a and -2 products, as well as associated browse and standard mapped image products).

4.4.2 Program Requirements

The level-3 QC program requires a level-3 product to process. In order to generate the parent level-2 boundaries, the parent level-2 products are also needed.

The level-3 QC program has the following hardware and software requirements:

- a) It can run on either an SGI workstation that has 8-bit color, or an X-terminal with 8-bit color;
- b) The host computer must have the IDL software and an IDL license;
- c) In order to use the Sybase database, the QC program must have access to the Sybase client software. This can either be the CALVAL computer, which has Sybase, or any computer which can access the client software via an nfs mount.

4.4.3 Program Operation

The level-3 QC program is started with the command `QC13int`. This can be followed (optionally) by the file name of the level-3 product to check. Upon startup, the level-3 QC program displays the **Main** interface (Fig. 24) to select the parameters to display. The **Main** interface calls the **Display** interface (Fig. 25) to display the data in image form. More information about the image is displayed by calling the **Information** interface (Fig. 26) from the **Display** interface.

4.4.3.1 Main Interface

The **Main** interface (Fig. 24) has the following functions: selecting the level-3 product, choosing the parameter to display and its method of display, and approving or disapproving the product in the Sybase database. The level-3 product is specified first. It can be specified at startup or it can be specified in the program by using the **Database Query** button.

Once the product is specified, a number of choices may be made to select the data which is displayed in image form. The parameter, such as normalized water-leaving radiances at 412 nm, $L_{WN}(412)\dagger$, is chosen from among the 12 standard level-3 parameters. The measure refers to the statistical measure of the data to display with the mean value as the default. The projection determines the map projection in which to display the data. The projection, combined with the latitude and longitude boundaries, determines the geographical portion of the data to view. A coastline map and latitude-longitude grid can also be selected to overlay the image. The scaling specifies the range of the numerical data values to be scaled into the image. The default (1,-1) scales the data so that the minimum and maximum of the data are linearly mapped into the minimum and maximum value of the displayed image. If

a LUT is chosen with the **Load LUT** button, the data values are displayed in false color, otherwise, a range of grey values are assigned to the data values (black is assigned to the lowest value and white to the highest).

An image of the chosen parameter is generated by pressing the **Create** button, which invokes the **Display** interface, described in the next section.

When the product has been examined and its quality has been determined, the QC status of the product is updated by pressing either the **Approve** or **Disapprove** button. An approval of a level-3 product confers automatic approval to all of the level-1a and -2 parent products (see Section 4.6 for more detail on the QC status codes).

When all level-3 QC procedures are completed, the **Quit** button is pressed to exit the level-3 QC program.

4.4.3.3 Display Interface

The **Display** interface (Fig. 25) displays the image of the level-3 product and graphic overlays selected by the **Main** interface. Access to the analysis and printing functions are also contained within this interface.

The image area displays the image of the selected parameter in grey values or in false color. A coastline map, a latitude-longitude grid, and the boundaries of the parent level-2 data sets can be displayed over the image to better locate landmarks and the extent of the data.

The **Function** button selects three functions that can be applied to the level-3 image. The **Cursor Position** function invokes the **Information** interface (see the next section), which shows quantitative information about the level-3 product. The **Postscript Output**, and **Save to File** functions are used to save the currently displayed image in either PostScript form or as an HDF data set.

The **Quit** button is pressed to exit the **Display** interface.

4.4.3.4 Information Interface

The **Information** interface (Fig. 26) displays quantitative information about the currently viewed parameter in the **Display** interface. It also allows the placement of the cursor at a designated location. The major functions are described here.

Many functions of the **Information** interface deal with determining information about a specific point in the image of the selected parameter within the **Display** interface. The location is specified and indicated by placing the cursor at the location on the image. The interface has two modes of using the cursor for positioning. In the interactive mode, whenever the cursor is in the image, the geographic-, line-, and pixel position of the cursor is updated in the interface's text areas. In the mouse button mode, the position is updated only when the left mouse button is pressed. The cursor can also be positioned at a particular latitude and longitude by entering the location in the latitude and longitude text areas and pressing

\dagger Represented in the GUI as `nLw_412`.

Interactive Software Mapping Program

Input file: Database Query Select

Product

Measure

Projection

Display Option:

☐ Grid ☐ Continents ☐ Data Window Size:

Center Lat/Lon : Rotation :

Lat Boundary : Lon Boundary:

Data Scaling, Min, Max: Set Default

Load LUT Create Setup Spin Quit

Database Disposition of File

Approve Disapprove

Fig. 24. This is the level-3 QC Main interface.

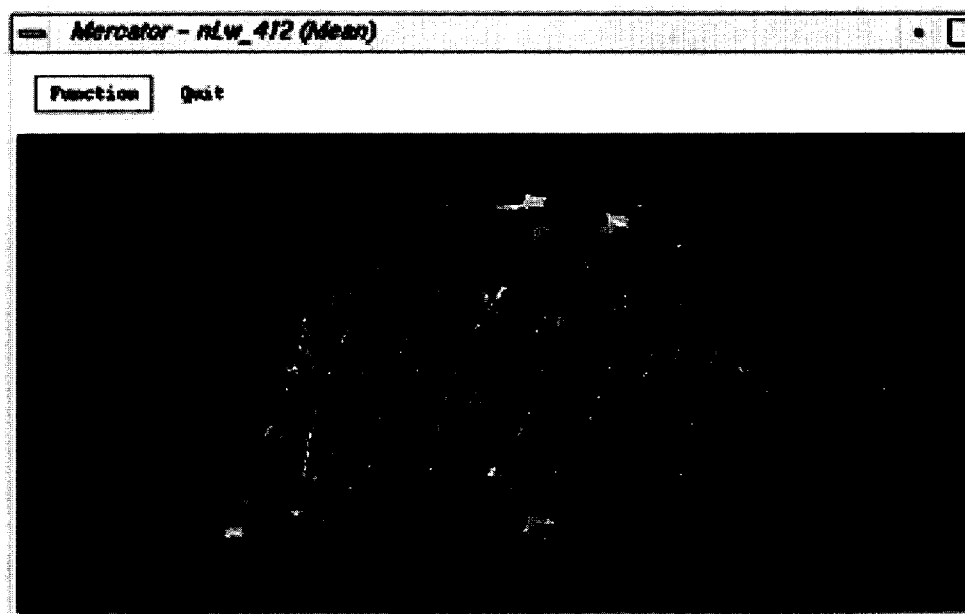


Fig. 25. This is the level-3 Display interface.

Display Mode: ☐ Interactive ☒ Mouse button

Pixel/Line Lat/Lon Image Data

271 / 237 -23.56 / 68.36 79.00

Or, place cursor at:

Latitude : -23.56

Longitude: 68.36

Data at a point:

File: /taftun4/wayne/SeaWiFS/data/l3/batch2/S1995171.L3b_DAY

Latitude: -23.55999 Longitude: 68.360001 Bin #: 1784614

Row: 798 Bin in row: 2732

of points in bin: 7 # of segments in bin: 1

Weight: 2.645751

	Mean	STD	Variance	Median
nLw_412	6.2036	0.013696	0.00018757	6.1
nLw_443	4.811	0.0097469	9.5001e-05	4
nLw_490	3.1156	0.0062275	3.8781e-05	3.1
nLw_510	2.022	0.0046581	2.1698e-05	2
nLw_555	1.2299	0.0044475	1.978e-05	1.1
La_670	0.71971	0.0013781	1.8992e-06	0.7
CZCS_pigment	0.03457	0.00053397	2.8513e-07	0.03
chlora	0.29586	0.0032582	1.0616e-05	0.2
K_490	0.034514	9.9775e-05	9.9551e-09	0.03
chlora/K_490	8.5721	0.094132	0.0088608	8.1
epsilon	1	0	0	
tau_865	0.10572	0.0018599	3.4592e-06	0.1

Parent List and Controls

Contrib.	Outline?	Level 2 Parent
YES		S1995171163154.L2_GAC
YES		S1995171145301.L2_GAC
YES		S1995171164716.L2_GAC
YES		S1995171212833.L2_GAC
YES		S1995171181047.L2_GAC
YES	YES	S1995171063837.L2_GAC
YES		S1995171045944.L2_GAC
YES		S1995171230725.L2_GAC
YES		S1995171194940.L2_GAC

Turn all outlines: ☒ On ☐ Off

Parent root

S1995171063837

Run QC on chosen parent

Fig. 26. This is the level-3 Information interface.

the **Place Cursor** button. The position in the latitude and longitude text areas is used for many information functions in this interface.

All the information at a level-3 bin specified by the latitude and longitude can be displayed by pressing the **Display Point Information** button, included are: geographic location, bin number, row and bin in row, number of points in the bin, and all the statistical measures for the 12 level-3 parameters.

When the **Information** interface is invoked, the level-2 parent products are determined and displayed in a list that is used to indicate the parent products of a selected point (*Contrib* column) and to indicate the products whose boundaries will be drawn on the image of the level-3 product (*Outline* column). Boundaries can be selected or deselected either by selecting the line in the list or by pressing the buttons to turn on or off all of the outlines. The selected boundaries—the boundaries whose *Outline* column contains a **Yes**—are drawn when the **Draw Boundaries** button is pressed. Parent level-2 products of a selected point are determined when the **Flag Parents of Point** button is pressed, resulting in a **Yes** appearing in the *Contrib* column beside every level-2 product that could contribute to the point.

Finally, the level-1a, -2, or -3 QC may be invoked on a parent product by selecting that parent from the list (its name appears in the parent root area) and pressing the button for running the appropriate QC function.

The **Quit** button is pressed to exit the **Information** interface.

4.4.4 Future Enhancements

The level-3 QC program satisfies all of the basic requirements and is ready for operational use. As time permits, a feature will be added to display the ancillary field data, such as surface pressure, ozone, and surface winds.

4.5 AUTOMATIC QC PROGRAMS

The automatic level-1a, -2, and -3 QC (AQC) program performs the easily automated initial integrity and gross data quality checks on the level-1a, -2, and -3 products immediately after they are created by the data processing programs.

The AQC program consists of two main functions. The first function is to check the integrity of the product against the specification for the product. This includes checking the proper format for all components that make up the product, and checking many of the items for consistency and reasonableness. The second function is to check the general data quality to verify that the data values and flag amounts are within reasonable thresholds. This can be easily done on SeaWiFS products because they include general metrics on the data quality. The quality of the level-3 product will be automatically checked by comparing the parameters to the average and standard deviation of the parameter over the life of the mission.

4.5.1 Program Requirements

The AQC program requires, as input, the file name of the product that will undergo the QC process and a format file that describes the organization and contents of the HDF data set that makes up the product (Darzi et al. 1995). In addition to these files, the level-3 AQC program requires a binned file containing all level-3 data accumulated during the life of the mission.

The only hardware and software requirement for the AQC program is that it has to run on an SGI machine and have access to the required files.

4.5.2 Program Operation

The AQC program is invoked with the command, `fmt_check`, followed by the type of data to undergo the QC process: level-1a, -2, or -3 data; the version of the archive specifications used (see Darzi et al. 1996); and the file name of the product to go through the QC process. Note that under operational conditions, the AQC program is invoked as part of the processing stream, immediately after the step that created the product.

Once started, the AQC program checks the product integrity and determines if the data quality metrics are within acceptable thresholds. It notes any problems in a report and sets a system status value to 0 (zero) if the product passed the QC checks; 1 if a program error occurred (faulty input files, etc.); 2 if a problem exists with the product itself; and 3 if both problems have occurred. This status is then used to update the product's QC status to either **Approved** or **Disapproved** by the AQC program. The AQC program's **Approved** status indicates a preliminary approval—the product must still be examined by the IQC program to approve it for archiving by the DAAC during normal operations. Section 4.6 discusses the QC status in more detail.

4.5.3 Future Enhancements

The portions of the AQC program that checks the data values will be implemented when there is more experience with the real data. Checking level-3 values against the binned values accumulated over the mission life must also wait until sufficient operational data is accumulated.

4.6 QC PROCEDURE DETAILS

Fig. 27 shows a detailed flow diagram of the level-1a, -2, -3, and ancillary data processing performed by both the SDPS and CVE groups, and includes the AQC for each step, as well as the processing of the browse and standard mapped images. The contribution of ancillary data to the processing is included in the figure and in the following discussion because of its important interaction in the data processing and QC process. Note that these procedures will be changed as more experience is gained with the simulated and operational data.

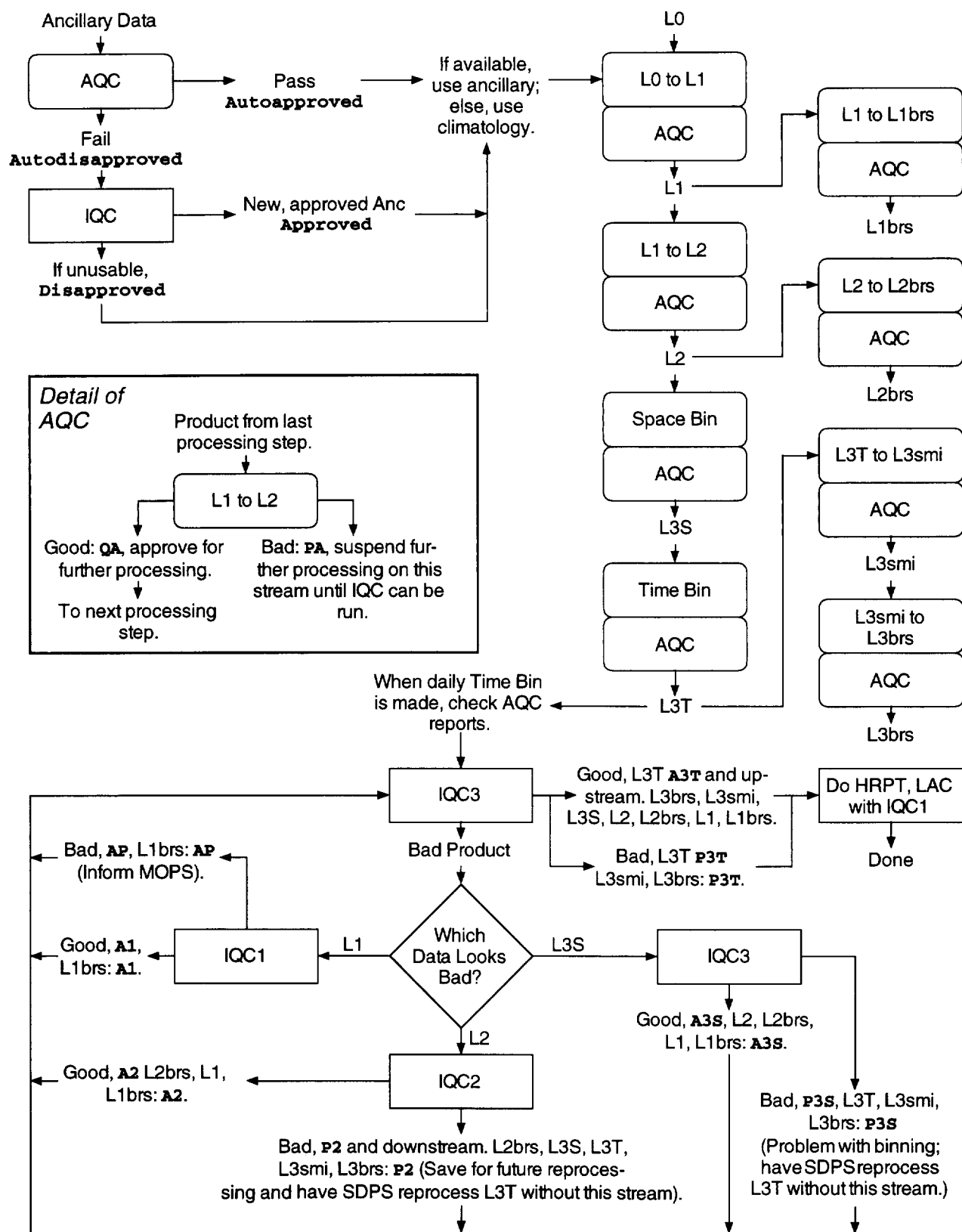


Fig. 27. Level-1a, -2, -3, and ancillary data processing are shown here. The QC status codes are explained in Table 4 and in the text.

Table 4. The codes that are important to QC processing.

Code	Description
PA	Problem found by the AQC.
QA	Approved by the AQC, still needs approval by the IQC before it can be sent to the DAAC.
A1	Approved by the level-1a IQC.
AP	Interactively approved level-1a product with a navigation problem (processing continues).
A2	Approved by examining the level-2 product.
P2	Disapproved by examining the level-2 product.
A3S	Approved by examining the level-3 space binned product.
P3S	Disapproved by examining the level-3 space binned product.
A3T	Approved by examining the level-3 time binned product.
P3T	Disapproved by examining the level-3 time binned product.

Extra notes:

1. *Approvals* propagate upstream. For example, if a time binned product is approved, the parent level-3 space binned, level-2, and level-1a products are approved.
2. *Problems* propagate downstream. For example, if a level-2 product has a problem, its children—the level-3 space binned and level-3 time binned products—have the problem code set.
3. The process of creating browse and standard mapped products should not encounter any problems once the programs are verified and the input data has the correct format. Thus, in normal operations, if a level-*x* product is approved, its browse (and the standard mapped product for the level-3 time bin) are approved without direct examination. The AQC program will be monitoring these products just in case.
4. Approvals and disapprovals propagate laterally—if a level-2 product is approved, the browse is also approved.
5. The propagation rules do not apply to the AQC program since they are unnecessary.

4.6.1 QC Codes

Although the real QC codes are numerical and there are more codes than this (required by the SDPS), Table 4 shows the codes that are important to QC processing.

4.6.2 AQC Function

The AQC function can stop the processing of data if it finds a problem. It stops the processing of one stream but not others. Time binning also proceeds without the stopped streams. The lack of ancillary data does not stop level-1a to level-2 processing—climatology data are used in this event (discussed in greater detail later).

The AQC function is the first to check the products and is run by SDPS immediately after a product is created. It checks the format and any quality values against thresholds. If any of these tests fail, that product will be disapproved and the proper failure status code is set (code PA). Otherwise, it is marked as *in progress* (code QA) to indicate it has been approved by the AQC function. The results of the AQC function (in the form of log files) are made available to the CVE before the IQC function is started.

At any point in processing, when the AQC function fails, the processing for that stream is halted until the IQC function can check it out. However, other processing streams proceed, as does the time binning, without the

problem stream. If the problem can be repaired, or if the IQC function determines that no problem exists, processing this stream can continue and the time binned product can be reprocessed to include this stream.

The AQC function of level-1a, -2, and -3 products currently consists of file integrity checks. The format of the data is checked and consistency between, and validity of, metadata is also checked. The AQC function checking includes the browse and level-3 standard mapped products. In the future, checks of the image data quality, such as threshold checks and file metrics, will be added.

4.6.3 GAC Interactive QC

QC checking of the data always begins with a check of the level-3 time binned product. Not only does this reduce the amount of interactive QC required, but it ensures that the status updates can propagate to all the products associated with the time binned product, i.e., all associated products have already been created.

The level-3 QC software queries the database to find the daily files that are ready (code QA). The **Ready** status indicates the level-3 time binned product is ready for the QC process and that the standard mapped product and the browse product have been created. If the product is approved, the approval is propagated to the browse and standard mapped products and upstream. Note that it is expected that at the start of operations, even the browse

and standard mapped products will be examined often until the programs are verified.

If a problem is seen in a portion of the level-3 product, the parent stream for that portion is identified and the interactive level-1a, -2, or -3 QC function is invoked on those data. If the level-1 product is checked and has a problem with navigation, its status code is set to AP, and Mission Operations is informed but processing is not disrupted. The level-1a product is approved otherwise (QC code A1 is set). Note that a gross navigation error (large distance errors in the position of a point) can only be identified when a land mass is nearby. Such a problem would most likely cause a rejection by the level-2 QC and the data would not get binned. In order to insure that these products do not inadvertently get binned, the level-2 QC will be run on any products whose parent level-1a products were assigned the QC code AP.

If the level-2 product is checked and has a problem that cannot be repaired by modifying the reprocessing parameters, the level-2 product and the accompanying browse and downstream files are given the QC code P2, indicating a problem. The time binned product will be reprocessed excluding this level-2 data. If and when new reprocessing parameters are derived, the parameter file name will be given to the data processing group so it can do reprocessing to include the missing level-2 files. It is expected that examination of a number of days of data will be required before a new set of parameters are considered for reprocessing. Then, all the data will be reprocessed with these new parameters so that a consistent set of products (having the same controls) is obtained. Initially, reprocessing single files (fix-on-the-fly) will not be undertaken, but will be incorporated once the processing procedures and algorithms are stable.

A single file level-2 reprocessing may also be necessary if a better set of ancillary data can be supplied. This can happen as the result of interactively approving ancillary data that were automatically disapproved, interactively modifying approved or disapproved ancillary data, or by obtaining ancillary data that were not available at processing time.

Once the checking of data in a stream is completed, control is returned to the level-3 QC function so that problems can be checked in any other stream within the same time binned product. In the situation where any product in a stream is disapproved, the entire daily file is disapproved until reprocessing can be done to omit or repair the bad parent products.

4.6.4 Interactive QC on Other Products

The level-1 and -2 QC will be able to access the LAC, HRPT, and other nonbinned GAC data independently. Remaining data, which have not been approved or disapproved, can also be checked. Note that only data to be archived will have to be checked.

4.6.5 Ancillary Data QC

The QC status codes used are as follows:

1. **Ready**, the product is ready, but no QC has been applied yet.
2. **Autoapproved**, the AQC ran and the product passed all quality tests. The product can be used in the level-1a to level-2 program.
3. **Autodisapproved**, the AQC ran and the product failed one or more of the quality tests. The level-1a to level-2 program will not use this product when creating the level-2 product.
4. **Approved**, the product or an alternate product has been passed by the IQC and can be used by the level-1a to level-2 program and subsequently passed to the DAAC.
5. **Disapproved**, no good products are available. The level-1a to level-2 program should proceed using other available ancillary data or climatology if no satisfactory ancillary data is available.

The ancillary data QC processing will have these steps and capabilities:

1. The AQC function is run by the SDPS immediately after the ancillary product is created; the AQC function either approves or disapproves the product. The approval code is **Autoapproved**, and the disapprove code is **Autodisapproved**. The AQC function checks to see that the percentage of points in the product that fall within 1, 2, and 3 standard deviations of the climatological mean are less than the specified thresholds.
2. CVE will use the interactive ancillary data QC program to check all ancillary data. For each product it will either:
 - a. Determine that the product is good and give it the code **Approved**;
 - b. Repair the ancillary data. The code **Approved** will be given to the repaired product, which will replace the original product. The original product will be renamed and given the status code of **Disapproved**; or
 - c. Unconditionally disapprove the product and give it the code: **Disapproved**. Level-1a to level-2 processing can proceed once the ancillary products are interactively quality controlled.
3. Level-1 to level-2 processing can use up to three ancillary meteorological and ozone products. The products are chosen by the following procedure.
 - a. First, only products that have been approved by the IQC function are considered. From this set of products, three ancillary products are chosen such that each of the products satisfies one of the three following conditions (one product

satisfies one condition). The first possible ancillary product is the nearest one preceeding the level-1a start time but is within 12 hours of the start time (24 hours for ozone).

- b. The second possible ancillary product is the closest one following the level-1a end time but is within 12 hours of the end time (24 hours for ozone).
- c. The time of the third possible ancillary product lies between the level-1a start and end times.

Under these conditions, from zero to three ancillary products may be available. If only one ancillary product is available, it is used with no interpolation. If two or three ancillary products are available, interpolation to the data time is done with the appropriate files. If no files are found, climatology files are used.

4. In order to ensure that sufficient ancillary data has a chance to go through the interactive QC process and be available for level-1a to level-2 processing, the

generation of level-2 products should not proceed until either the optimum ancillary data is received or a specified waiting period has expired. Due to the limited length of this waiting period, interactive QC of the ancillary data should be done as quickly as possible.

5. CVE will receive the raw ancillary data from SDPS and archive it for future use, such as reprocessing, using better ancillary data repair algorithms.

4.6.6 Testing Modes

For testing purposes, changes can be made in the quantity of QC that is required before products can be sent to the DAAC. Three levels can be set:

- i) Send data to the DAAC only if the interactive QC has approved the product (operational mode);
- ii) Send data to the DAAC that has been approved by the automatic QC; or
- iii) Send all data to the DAAC.

Chapter 5

SeaWiFS Derived Product Validation Software

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ABSTRACT

The SeaWiFS derived product validation software was developed to compare SeaWiFS level-2 data with *in situ* data in order to assist in evaluating the sensor performance and the accuracy of the level-2 algorithms. The software will be used as part of an effort that will proceed continuously after launch to verify that the data generated by the SeaWiFS Project for archiving and distributing meet the required accuracy. The software will also be used to test algorithms alternative to those used operationally. An overview of this derived product validation software and its use is presented herein.

5.1 INTRODUCTION

CZCS, which flew aboard the NIMBUS-7 satellite from 1978–86, was the first satellite instrument to collect ocean color data. Although it was a proof-of-concept sensor, CZCS was highly successful in demonstrating the scientific utility of such data; it also exposed a number of problems that must be addressed during future missions (McClain et al. 1992). As a second generation ocean color instrument, SeaWiFS provides important improvements over CZCS with respect to sensor design and algorithms for the derivation of geophysical (level-2) data. These improvements include:

- 1) A greater numerical dynamic range of the radiance measurements with digitization of 10 bits instead of 8;
- 2) Onboard, postlaunch solar and lunar calibrations;
- 3) Sensor engineering telemetry data;
- 4) A higher signal-to-noise ratio; and
- 5) Greater spectral resolution with a higher frequency band (410 nm) to separate chlorophyll *a* from degradation by-products, and lower frequency bands (765 nm and 865 nm) for atmospheric correction in turbid waters.

The maximum uncertainty goals for SeaWiFS data are 5% for water-leaving radiances and 35% for chlorophyll *a* concentrations in Case-1 waters (Mueller and Austin 1995).

One important lesson learned from the CZCS mission is that the sensor's calibration should be monitored closely

and robust algorithms must be developed (Evans and Gordon 1994). For SeaWiFS, the sensor stability will be periodically checked by solar and lunar observations (Woodward et al. 1993 and Eplee et al. 1996). Vicarious calibration will also be performed to fine tune the satellite data with *in situ* measurements to ensure proper sensor calibration. Some of the *in situ* measurements will be used for algorithm development and for vicarious calibration. Other *in situ* data will be considered as sea-truth values and used as independent measurements for satellite-derived product validation, such as the analysis performed by Balch et al. (1992) for the CZCS global data set.

This validation procedure requires that surface measurements be matched with concurrent SeaWiFS measurements. The derived product validation software was designed to perform comparisons between satellite and *in situ* data in order to gauge the accuracy of SeaWiFS data and to help evaluate the quality of the sensor calibration and level-2 algorithms.

5.2 MATCH-UP METHODOLOGY

The validation of satellite data involves the spatial and temporal matching of such data with *in situ* data for comparison. The surface observations can include measurements from ships taken along the ship course or at stations, and from drifting and fixed buoys. These data are archived by the CVE and their metadata, e.g., time span and areal coverage, are cataloged in the *in situ* database. A detailed description of the *in situ* data can be found in Hooker et al. (1994). The satellite image data will be

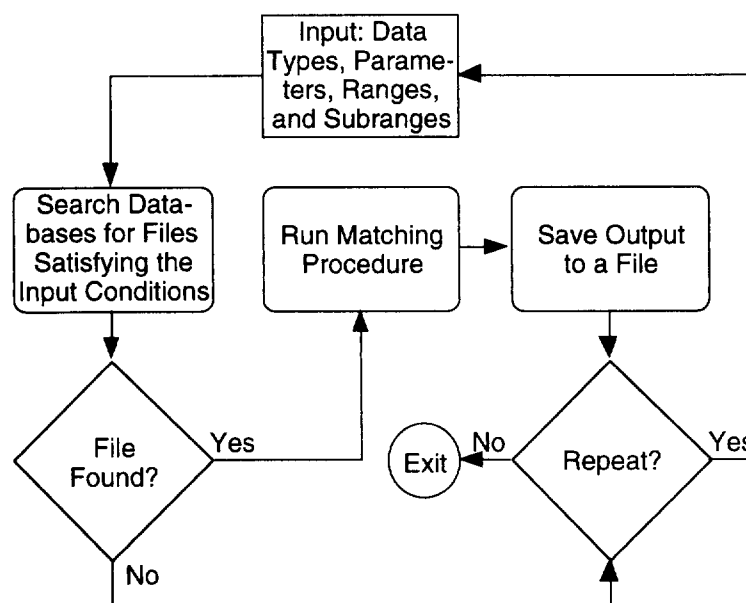


Fig. 28. This schematic diagram indicates the logical steps involved in the SeaWiFS derived product validation match-up process. The allowed input are: observation data type, satellite data type, parameters, temporal and spatial ranges, and temporal and spatial tolerance subranges.

produced by the SDPS and delivered to the GSFC DAAC after they pass QC (Hooker et al. 1992 and Robinson et al. 1996). At the same time, the SDPS will maintain a master database to keep track of all processed satellite scenes. The CVE also has a database of satellite scenes which will be a subset of the SDPS database. This subset will contain scenes used primarily for derived product validation match-up purposes.

Figure 28 depicts the general steps followed when performing the satellite derived product validation. The surface data are classified as along-track, buoy, cast, drifter, or fixed mooring. The image data type can be a SeaWiFS level-1 or -2 product of LAC or GAC resolution. The input parameter is used as a primary key to identify a unique common field between surface and image data. Secondary parameters, a list of SeaWiFS level-1 or -2 band names, can be selected after the primary key is defined.

The specification of temporal and spatial ranges is required to seek surface and image data files from the databases. At least one surface data file and satellite scene are required for the program to perform a matchup. The specifications of temporal and spatial tolerance subranges can relax the point-to-point data matching to point-within-region matching. The results of the matching are saved into an ASCII output file.

A user is required to input the data types, parameter, temporal and spatial ranges, and the name of an output file in which to save the match-up results. This information is entered through widgets of an IDL GUI. The derived product validation program's GUI is shown in Fig. 29. Each entry has a default value to illustrate the proper input syntax. For the output file name, a user can either type in a

full file name or press the **SELECT** button to choose a file path and name from existing files. If the output file exists, results from the matchup will be appended to it, otherwise, results will be saved to a new file.

A pull-down menu is used to enter the data type. From the **IMG** button, a user has to select one SeaWiFS image data type and one primary parameter in order to run a matchup (Fig. 30). The secondary (minor) parameter menu will appear once the primary key is defined (Fig. 31). This multiple choice menu of secondary parameters is a list of either SeaWiFS level-1 bands or level-2 products. The user may select, any, all, or none of the listed secondary parameters. The purpose of the secondary keys is to generate additional means and standard deviations for these parameters from the image file to assist in algorithm evaluation.

A time subrange may be entered to specify the temporal mismatch tolerance of data matchup. The default time subrange is $[-15,15]$ in units of minutes. This default range will allow a data pixel viewed at 1200 Greenwich Mean Time (GMT), for example, to be matched with a sea-truth measurement made between 1145 and 1215. To specify simultaneous measurements, the time subrange should be set to $[0,0]$, making the time tolerance less than 30 seconds. The maximum allowable time subrange is $[-60,60]$.

Similarly, an image area subrange may be entered to specify the spatial tolerance in terms of pixels (**X_SIZE** in the output file) and lines (**Y_SIZE** in the output file). The default image area is $[3,3]$, or 3 pixels \times 3 lines, centered over the surface position. Within this spatial range, the mean and standard deviation for the satellite pixels will be calculated in order to gauge the homogeneity of the

Output to:	<input type="text" value="~/"/>		<input type="button" value="SELECT"/>
Environmental data:	<input type="button" value="ENV"/>	<input type="text" value="ENV.drifter"/>	
Image data:	<input type="button" value="IMG"/>	<input type="text" value="IMG.Level-1 GAC.865 nm"/>	
Date range (YYYYMMDD):	<input type="text" value="19910101, 20201231"/>		
Time range (HHMMSS):	<input type="text" value="000000, 235959"/>		
Latitude(-90:90) south to north:	<input type="text" value="-90., 90."/>		
Longitude(-180:180) west to east:	<input type="text" value="-180., 180."/>		
Use environmental data within <input type="text" value="-15, 15"/> (minutes) of image time.			
Use image data area <input type="text" value="3, 3"/> (pixels,lines) around environmental point.			
<input type="button" value="RUN"/> <input type="button" value="SAVE"/> <input type="button" value="RESTORE"/> <input type="button" value="EXIT"/>			
<div style="border: 1px solid black; height: 150px; width: 100%;"></div>			

Fig. 29. The main GUI of the derived product validation program is shown in this figure.

Output to:

Environmental data:

Image data:

Date range (YYYYMMDD):

Time range (HHMMSS):

Latitude(-90:90) south to north:

Longitude(-180:180) west to east:

Use environmental data within (min, max)

Use image data area (pixels, lines) and

Level-1 GAC ▾
 Level-1 LAC ▾ 201231
 Level-2 GAC ▾
 Level-2 LAC ▾ 59

nLw_412
 nLw_443
 nLw_490
 nLw_510
 nLw_555
 La_670
 La_865
 CZCS_pigment
 chlor_a
 K_490
 epsilon
 tau_865

Fig. 30. Shown here is the main GUI of the derived product validation program showing the IMG pulldown menu.

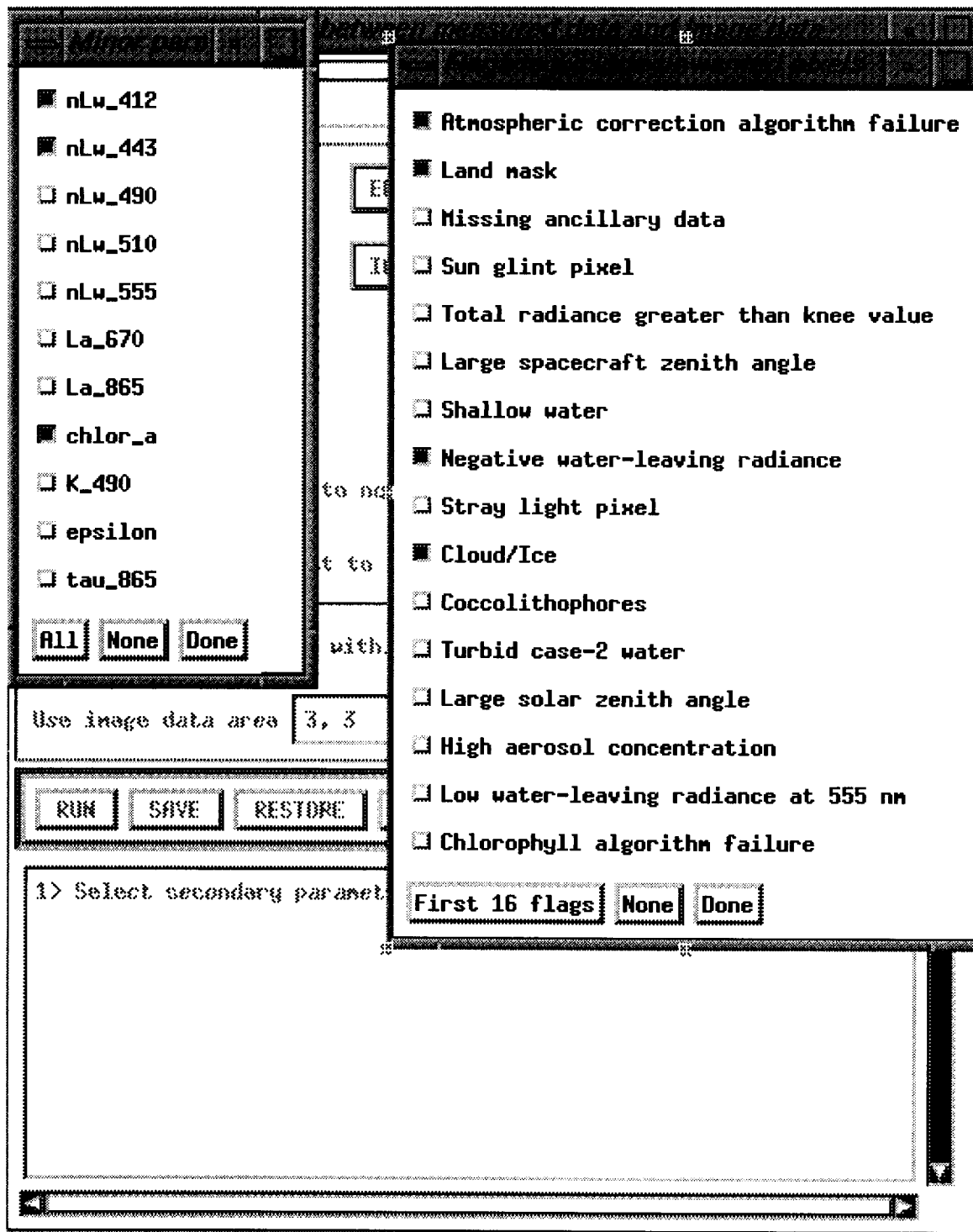


Fig. 31. The main GUI of the derived product validation program shows the secondary parameter and level-2 flag selection menus.

Table 5. Descriptions of fields (columns) for each result of a product validation matchup stored as a record in an ASCII file.

Column	Description
1	Satellite image file name with file path.
2	Year of image data.
3	Month of image data.
4	Day of image data.
5	Hour of image data.
6	Minute of image data.
7	Second of image data.
8	Time difference (minutes) between <i>in situ</i> and satellite values (V_I and V_S , respectively).
9	Solar zenith (degrees).
10	Solar azimuth (degrees).
11	Satellite zenith (degrees).
12	Satellite azimuth (degrees).
13	Satellite tilt (degrees).
14	Number of pixels, X_SIZE, around matched image data.
15	Number of lines, Y_SIZE, around matched image data.
16	Latitude (degrees).
17	Longitude (degrees).
18	Valid number of counts from X_SIZE by Y_SIZE domain.
19	Standard deviation calculated from X_SIZE by Y_SIZE of image domain.
20	Mean value calculated from X_SIZE by Y_SIZE of image domain.
21	<i>In situ</i> observation value (V_I).
22	Percent relative error between satellite and <i>in situ</i> values: $100(V_S - V_I)/V_I$.
23	Parameter name of primary parameter.
24	Condensed <i>in situ</i> observation file name with file path.
25	Original <i>in situ</i> observation file name.
26	Observed <i>in situ</i> data type (along track, station, drifter, buoys...).
27	Name of experiment or project during which <i>in situ</i> data were collected.
28	Name(s) of investigators responsible for <i>in situ</i> data.
29	Standard deviation of second parameter.
30	Mean of second parameter.
31	Name of second parameter.
...	
.	Standard deviation of N th parameter.
.	Mean of N th parameter.
n	Name of N th parameter.
$n + 1$	Algorithm name of first level-2 flag.†
...	
$n + m$	Algorithm name of m th level-2 flag.†

† Level-2 pixels for which these flags were set were excluded from match-up calculations.

satellite data surrounding the surface point for comparison with the sea-truth value. The allowable values for X_SIZE and Y_SIZE are 0–15.

For level-2 products, each pixel is associated with a 16-bit quality flag field, `12_flags`, each bit of which is used to indicate quality conditions for that pixel (McClain et al. 1995). In the derived product validation program, quality flags may be selected such that, if they are set, the associated pixels are excluded from the calculations of the mean and standard deviation. Pixels with flag bits set for land, cloud, or ice, for example, should obviously be

excluded in this manner. The level-2 quality flag selection menu is also shown in Fig. 31.

All entered values can be saved by pressing the **SAVE** button. The processing status will be displayed in the text widget to indicate whether or not the selected command was completed successfully. The saved values can also be recalled by pressing the **RESTORE** button. Input, including secondary parameters and level-2 quality flag selections, will then be updated automatically.

When the **RUN** button is pressed, the program searches the CVE database of satellite products and the *in situ* da-

Table 6. Possible plots and associated statistical analyses for the evaluation of product validation match-up results. (The numbers under the *Example* column refer to figures found in this chapter.)

Plot Category	Specific Plot Types	Analyses	Example
Plot	Geolocation map	Data Locations	7
Time Series	Latitude plot	[1]	8
	Longitude plot	[1]	8
	Relative error plot	[1]	8
V_S vs. V_I	Scatterplot	[2]	9
	Cross correlation plot	Data Shifting Test	9
	Time series plot	[1] [3]	9
	Histogram	[4]	9
Relative Error (RE)	Satellite data vs. RE plot	[1]	10
	Latitude data vs. RE plot	[1]	10
	Longitude data vs. RE plot	[1]	10
	Solar zenith angle vs. RE plot	[1]	10
	Solar azimuth angle vs. RE plot	[1]	10
	Satellite zenith vs. RE plot	[1]	10
	Satellite azimuth vs. RE plot	[1]	10
	Time difference between V_I and V_S vs. RE plot	[1]	10

[1] Correlation coefficient, linear fit, minimum, and maximum.

[2] Correlation coefficient and linear fit.

[3] Date and time, number of records, mean, variance, skewness, kurtosis, and standard deviation.

[4] Bin size, number of bins.

tabase for scenes and data of the primary key that satisfy the temporal and spatial restrictions. If some of both satellite and *in situ* data are found, the program calculates and tabulates the results for output. If no matching data are found, or if other errors occur, appropriate messages are issued to the text window instead. Users can then either enter new selections to continue data matching or press the EXIT button to quit.

All *in situ* and image files used for matchups must be entered in the CVE database. The program, however, will also search the SDPS master database for scenes that are not in the CVE database but that can be used for a given matchup. If such scenes are found, a widget is displayed listing the scenes available from SDPS and those available from the DAAC, and advising the user on the need to obtain these products.

Results from matched data points are saved to the user specified file, which is in an ASCII column and row format. The output will be appended to a file if the file already exists. Each column in the file is separated by a comma. The columns (record fields) of the output file are listed in Table 5. By the selection of level-2 quality flags, it is possible that within the X_SIZE by Y_SIZE image domain no valid pixels exist. In such a case, the mean, standard deviation, and percent relative error are written as 9999.0. Information concerning secondary parameters and level-2 flags will be stored in the file only if some have been selected by the user.

A future capability will be to allow a user to specify a tolerance for the match-up results between level-2 images and *in situ* data. If a match-up difference is greater than that value, the level-2 QC program would be automatically invoked with that image (Robinson et al. 1996). This allows for visual inspection of the scene to see if the *in situ* observations are near frontal boundaries, flagged or masked pixels, or other irregular data. Also, the analyst would then be able to use this program to reprocess the level-2 image using alternate input parameters or other algorithms implemented in that program for testing purposes. The reprocessed level-2 images could then be used in the matchup to see if improved agreement with the *in situ* data is obtained.

5.3 MATCH-UP EVALUATION

Results from matched satellite and *in situ* data points need further evaluation to quantify the accuracy and the limitations of the level-2 algorithms. Figure 32 depicts the general steps followed when performing the match-up evaluation. Based on the output file structure, shown in Table 5, data records can be selected with the combinations of ranges for spatial, temporal, and other variables. Once desired data are selected, they can be analyzed by means of plots and statistical analyses. Table 6 lists the 16 plots that may be generated and the statistical analyses that may be used in conjunction with each.

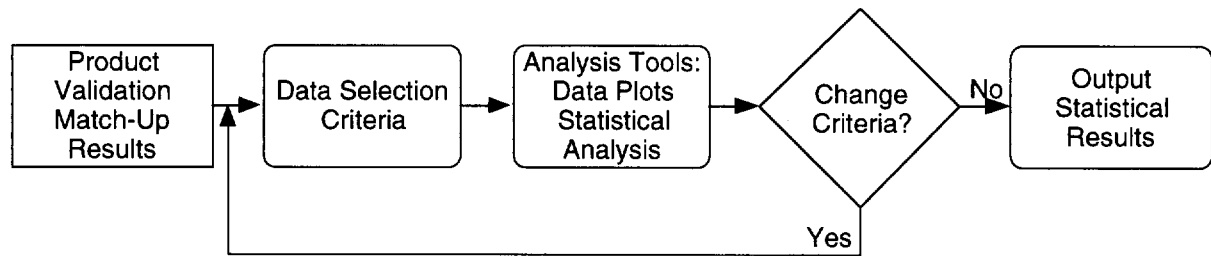


Fig. 32. A schematic diagram is presented, indicating the logical steps involved in the evaluation of results from the SeaWiFS derived product validation match-up process.

The screenshot shows the main GUI of the product validation evaluation program. It features several input fields and buttons. At the top, there are two rows of input fields: 'Match-up file:' with a text box containing '~/' and a 'SELECT' button, and 'Output to:' with a text box containing '~/' and a 'SELECT' button. Below these are four rows of input fields for ranges: 'Date range (YYYYMMDD):' with '19910101, 20201231', 'Time range (HHMMSS):' with '000000, 235959', 'Latitude(-90:90) south to north:' with '-90., 90.', and 'Longitude(-180:180) west to east:' with '-180., 180.'. At the bottom left, there are two buttons: 'RUN' and 'EXIT'. A large empty rectangular area with a vertical scrollbar is located at the bottom right, likely for displaying output or logs.

Fig. 33. The main GUI of the product validation evaluation program is shown above.

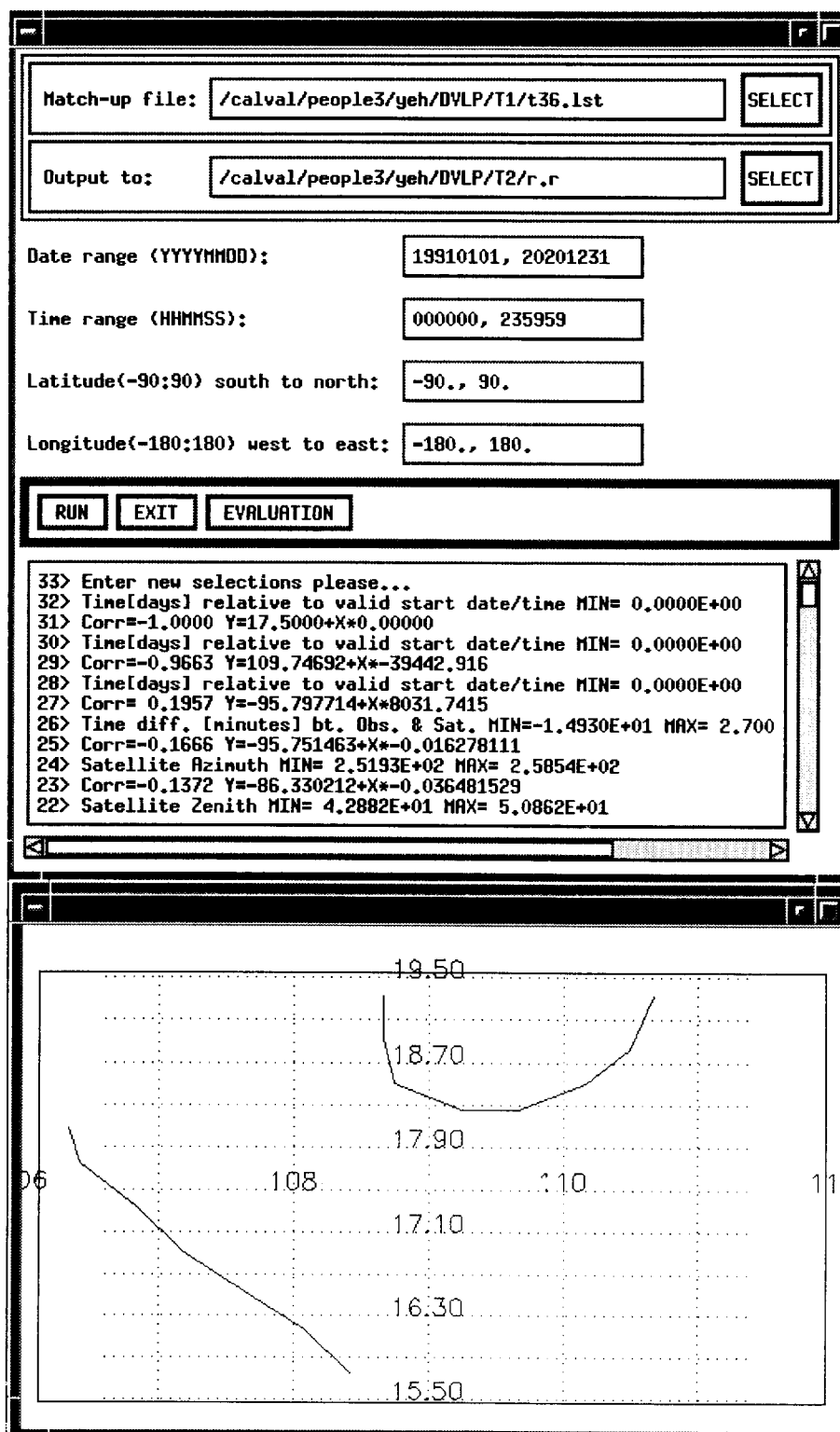


Fig. 34. The main GUI of the product validation evaluation program shows the geolocation map obtained after an analysis run.

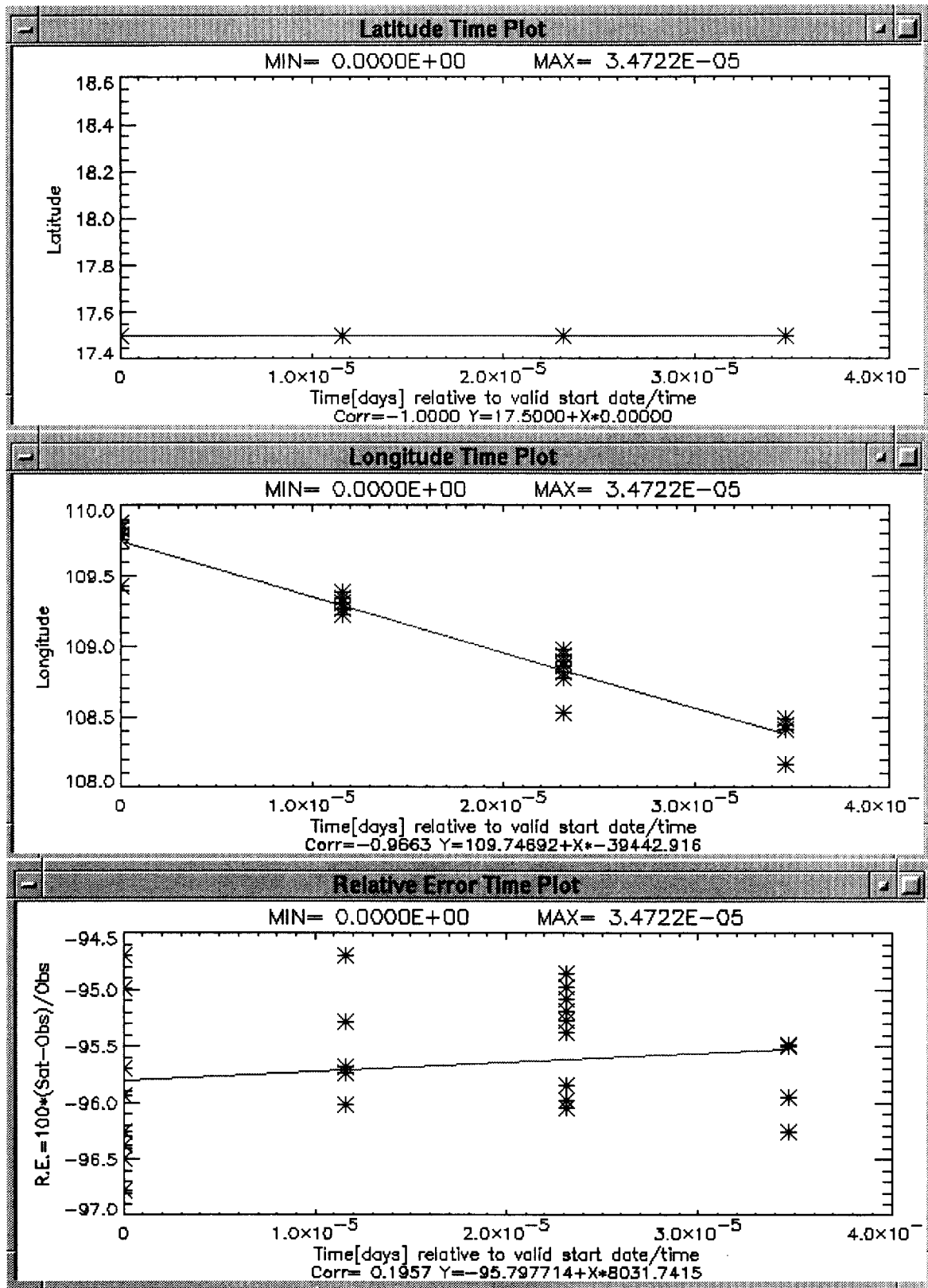


Fig. 35. Latitudes, longitudes, and relative errors of match-up data are being evaluated, plotted against time.

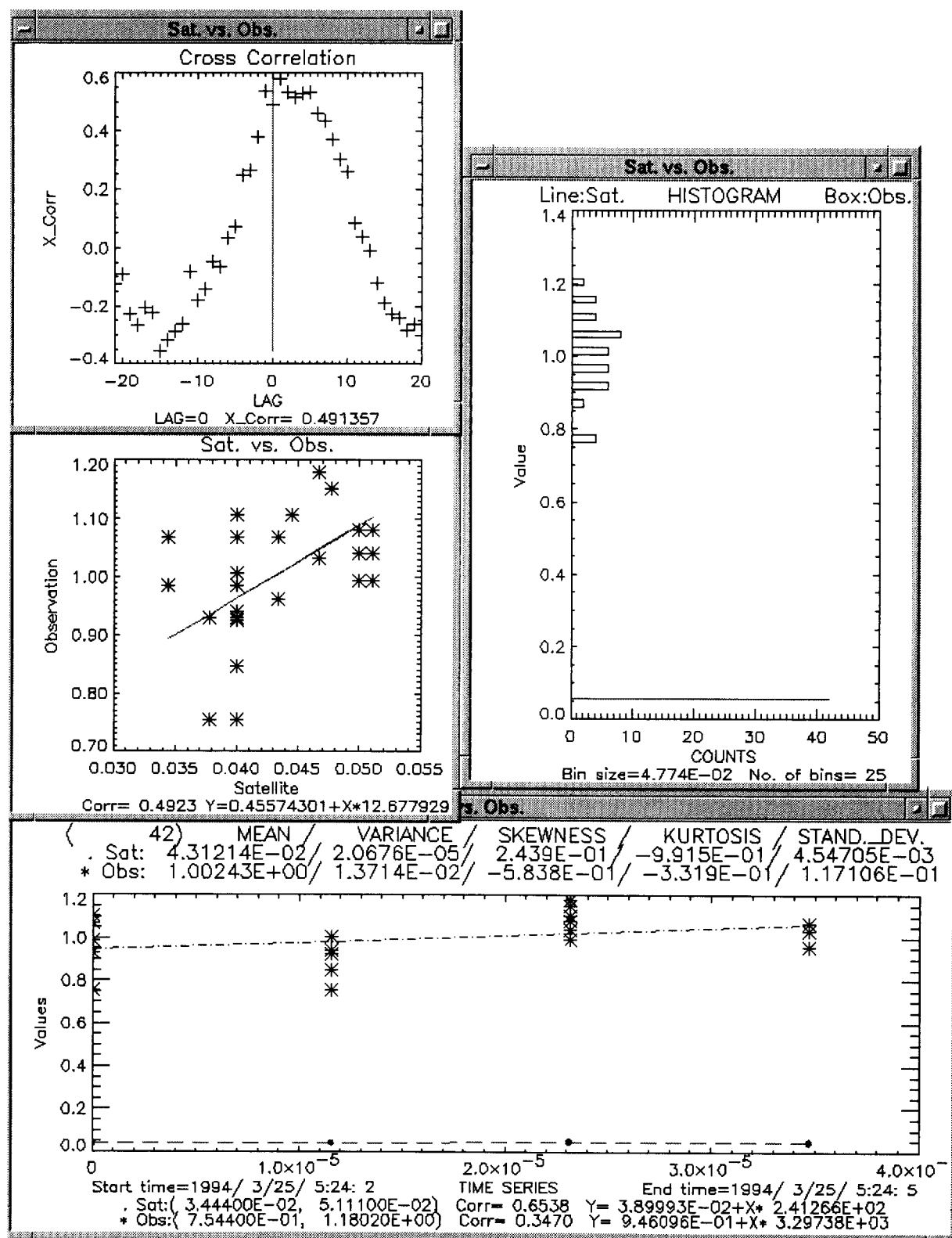


Fig. 36. A histogram, scatter plot, time trend, and cross correlation for satellite and *in situ* data are used to evaluate the correlation of the two data sets.

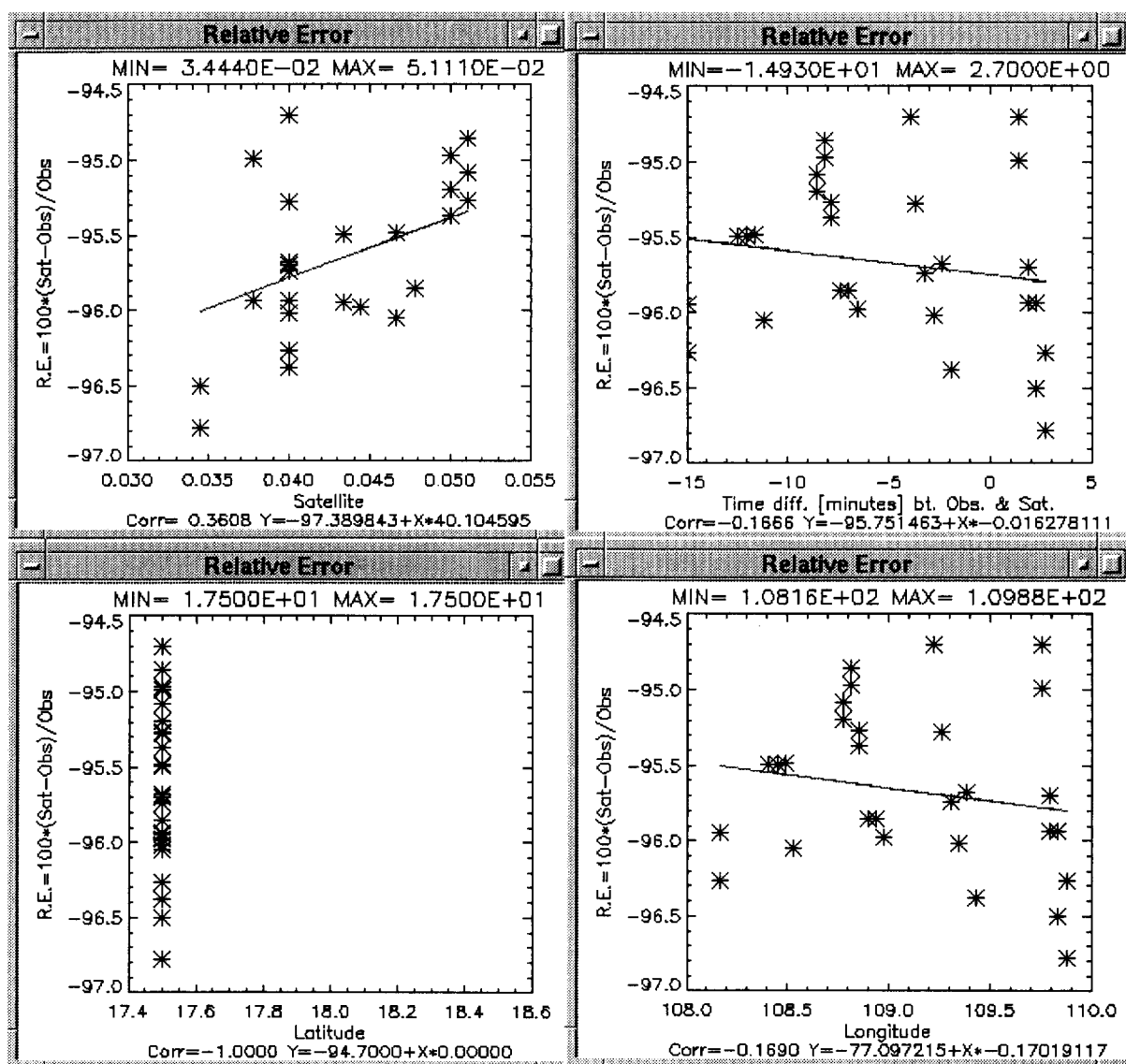


Fig. 37. a) A plot of the relative errors of satellite, time differential, latitude, and longitude versus other variables are used to show correlations of error with these variables allowing the user to select reasonable ranges for further analyses.

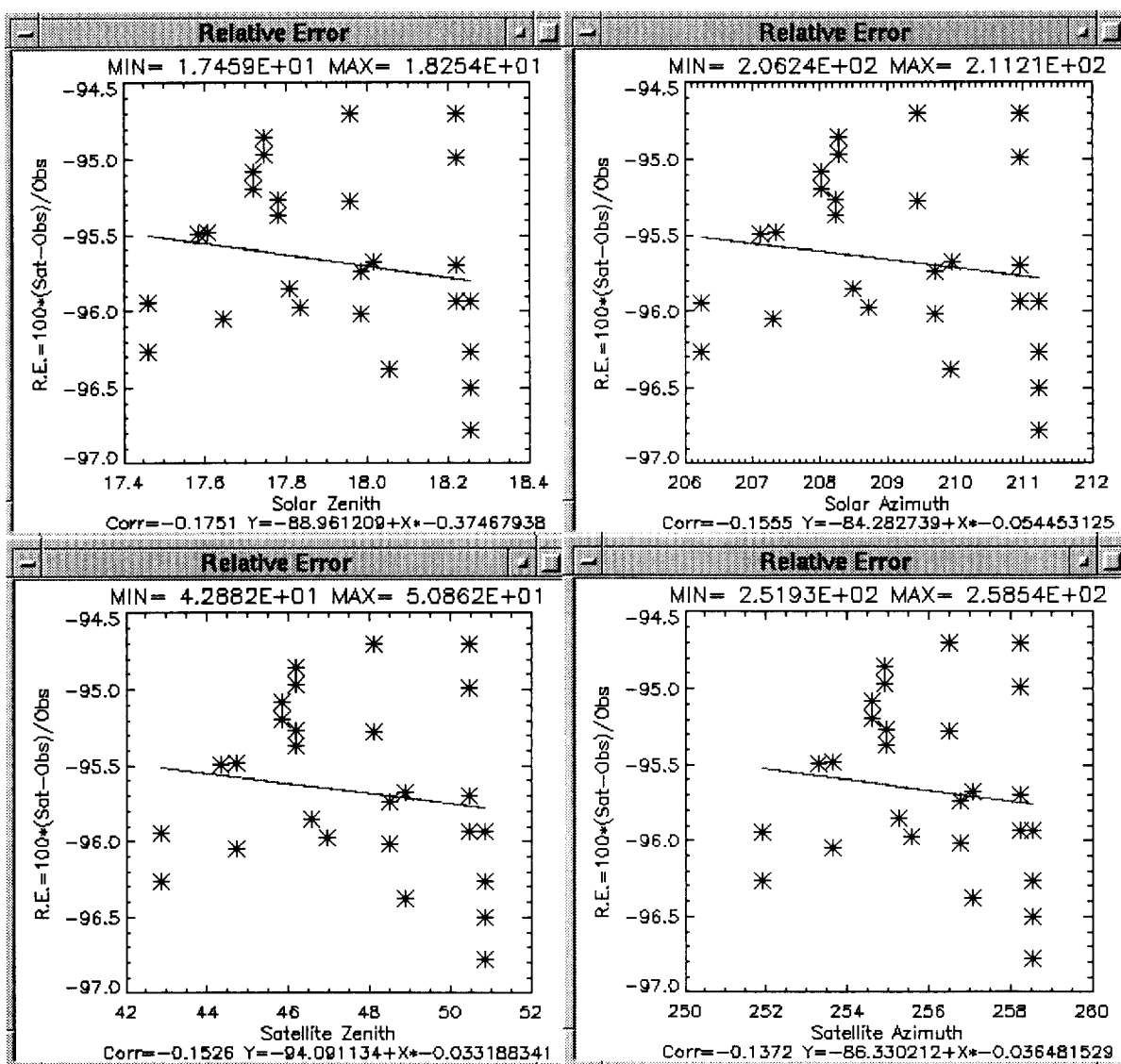


Fig. 37 (cont.) b) As in Fig. 37a, although this is a plot of the relative errors of solar zenith, azimuth satellite zenith, and azimuth versus other variables to show correlations of error with these variables allowing the user to select reasonable ranges for further analyses.

Product Validation Match-up Evaluation

MATCH-UP FILE: /calval/people3/yeh/DVLP/T1/t36.lst
 OUTPUT TO: /calval/people3/yeh/DVLP/T2/r.r
 DATE RANGE(YYYYMMDD): 19910101, 20201231
 TIME RANGE(HHMMSS): 000000, 235959
 LATITUDE: -90.0000, 90.0000
 LONGITUDE: -180.0000, 180.0000

Data Type:

Experiment:

Investigator:

Primary Key:

Satellite Value [0.03444, 0.05111]:

Relative Error(%) [-96.780, -94.700]:

Time Difference(minutes) [-14.930, 2.700]:

Solar Zenith Angle [17.4590, 18.2540]:

Solar Azimuth Angle [206.2400, 211.2130]:

Satellite Zenith Angle [42.8820, 50.8620]:

Satellite Azimuth Angle [251.9280, 258.5440]:

Date(YYYYMMDD) [19940325, 19940325]:

Time(HHMMSS) [052402, 052405]:

Latitude [17.5000, 17.5000]:

Longitude [108.1630, 109.8780]:

Fig. 38. The GUI shown is for evaluating match-up results using ranges obtained from a previous run to restrict data in the following analysis.

Table 7. SeaWiFS level-1 image database field names relevant to match-up processing.

<i>Field Name</i>	<i>Data Type</i>	<i>Comment</i>
l1_pathname	string (≤ 128 char.)	Image file directory path
l1_filename	string (30 char.)	Image file name
start_time	date/time	Time of first scan line
datatype	string (20 char.)	LAC, GAC, HRPT
stop_time	date/time	Time of last scan line
lower_left_lat	8-byte real	
lower_left_lon	8-byte real	
lower_right_lat	8-byte real	
lower_right_lon	8-byte real	
upper_left_lat	8-byte real	
upper_left_lon	8-byte real	
upper_right_lat	8-byte real	
upper_right_lon	8-byte real	

Table 8. SeaWiFS level-2 image database field names relevant to match-up processing.

<i>Field Name</i>	<i>Data Type</i>	<i>Comment</i>
l2_pathname	string (≤ 128 char.)	Image file directory path
l2_filename	string (30 char.)	Image file name
datatype	string (20 char.)	LAC, GAC, HRPT
l1_pathname	string (≤ 128 char.)	Image file directory path
l1_filename	string (30 char.)	Image file name

Table 9. Field names for the database table of *in situ* data.

<i>Field Name</i>	<i>Data Type</i>	<i>Comment</i>
start_date	string (9 char.)	
start_time	string (9 char.)	
end_date	string (9 char.)	
end_time	string (9 char.)	
start_latitude	8-byte real	
start_longitude	8-byte real	
end_latitude	8-byte real	
end_longitude	8-byte real	
investigator	string (≤ 255 char.)	Contact person(s)
affiliation	string (≤ 255 char.)	
experiment	string (≤ 255 char.)	
data_type	string (≤ 255 char.)	Along track, station, drifter, buoys...
sequence_number	4-byte integer	For cast data
original_file	string (≤ 255 char.)	Original filename
archive_file	string (≤ 255 char.)	Condensed filename
column_headers	string (≤ 255 char.)	Describes column content
south_latitude	8-byte real	Geographic extent of data
north_latitude	8-byte real	
west_longitude	8-byte real	
east_longitude	8-byte real	

Table 10. Field names for the database table of validation match-up results.

<i>Field Name</i>	<i>Data Type</i>	<i>Comment</i>
create_time	date/time	
pathname	string (≤255 char.)	
filename	string (≤255 char.)	
env_type	string (≤255 char.)	Along track, station, drifter, buoys...
img_level	string (≤255 char.)	Level-1, level-2
img_type	string (≤255 char.)	LAC, GAC, HRPT.
primary	string (≤255 char.)	Primary parameter name.
secondary_1	string (≤255 char.)	Secondary parameter name(s) (up to 11 names).
secondary_2	string (≤255 char.)	
secondary_3	string (≤255 char.)	
secondary_4	string (≤255 char.)	
secondary_5	string (≤255 char.)	
secondary_6	string (≤255 char.)	
secondary_7	string (≤255 char.)	
secondary_8	string (≤255 char.)	
secondary_9	string (≤255 char.)	
secondary_10	string (≤255 char.)	
secondary_11	string (≤255 char.)	
flag_1	string (≤255 char.)	Level-2 pixels for which these flags (up to 16) were set and which were excluded from match-up calculations.
flag_2	string (≤255 char.)	
flag_3	string (≤255 char.)	
flag_4	string (≤255 char.)	
flag_5	string (≤255 char.)	
flag_6	string (≤255 char.)	
flag_7	string (≤255 char.)	
flag_8	string (≤255 char.)	
flag_9	string (≤255 char.)	
flag_10	string (≤255 char.)	
flag_11	string (≤255 char.)	
flag_12	string (≤255 char.)	
flag_13	string (≤255 char.)	
flag_14	string (≤255 char.)	
flag_15	string (≤255 char.)	
flag_16	string (≤255 char.)	
start_time	date/time	Data selection date and time range.
end_time	date/time	
south_latitude	8-byte real	Data selection latitude range.
north_latitude	8-byte real	
west_longitude	8-byte real	Data selection longitude range
east_longitude	8-byte real	
sub_time_1	4-byte integer	Match-up time tolerance range.
sub_time_2	4-byte integer	
sub_pixel	4-byte integer	Match-up areal tolerance range (in pixels).
sub_line	4-byte integer	

Table 11. Field names for the database table of match-up evaluation results files.

<i>Field Name</i>	<i>Data Type</i>	<i>Comment</i>
create_time	date/time	
match-up_file	string (≤ 255 char.)	Match-up results file name.
pathname	string (≤ 255 char.)	Evaluation output directory path.
filename	string (≤ 255 char.)	Evaluation output file name.
start_time	date/time	Data selection date and time range.
end_time	date/time	
south_latitude	8-byte real	Data selection latitude range.
north_latitude	8-byte real	
west_longitude	8-byte real	Data selection longitude range.
east_longitude	8-byte real	
data_type_1	string (≤ 255 char.)	<i>In situ</i> data types (along track, station, drifter, buoys...; up to 7).
data_type_2	string (≤ 255 char.)	
data_type_3	string (≤ 255 char.)	
data_type_4	string (≤ 255 char.)	
data_type_5	string (≤ 255 char.)	
data_type_6	string (≤ 255 char.)	
data_type_7	string (≤ 255 char.)	
experiment_1	string (≤ 255 char.)	<i>In situ</i> collection experiment or project name (up to 7).
experiment_2	string (≤ 255 char.)	
experiment_3	string (≤ 255 char.)	
experiment_4	string (≤ 255 char.)	
experiment_5	string (≤ 255 char.)	
experiment_6	string (≤ 255 char.)	
experiment_7	string (≤ 255 char.)	
investigator_1	string (≤ 255 char.)	Contact person(s) corresponding to each experiment name.
investigator_2	string (≤ 255 char.)	
investigator_3	string (≤ 255 char.)	
investigator_4	string (≤ 255 char.)	
investigator_5	string (≤ 255 char.)	
investigator_6	string (≤ 255 char.)	
investigator_7	string (≤ 255 char.)	
primary	string (≤ 255 char.)	Primary parameter name.
value_1	8-byte real	Data value selection range
value_2	8-byte real	for primary parameter.
r_error_1	8-byte real	Primary parameter relative error selection range.
r_error_2	8-byte real	
t_diff_1	8-byte real	Time difference selection range.
t_diff_2	8-byte real	
sun_z_1	8-byte real	Solar zenith angle selection range.
sun_z_2	8-byte real	
sun_a_1	8-byte real	Solar azimuth angle selection range.
sun_a_2	8-byte real	
sat_z_1	8-byte real	Satellite zenith angle selection range.
sat_z_2	8-byte real	
sat_a_1	8-byte real	Satellite azimuth angle selection range.
sat_a_2	8-byte real	

Table 11. (cont.) Field names for the database table of match-up evaluation results files.

Field Name	Data Type	Comment
time_1	date/time	Date and time selection range.
time_2	date/time	
lat_1	8-byte real	Latitude selection range.
lat_2	8-byte real	
lon_1	8-byte real	Longitude selection range.
lon_2	8-byte real	

Figure 33 shows an IDL program that allows the analyst to select match-up records based on date, time, latitude and longitude for plotting and performing statistical analyses. A map with latitudes, longitudes, and coastlines may be displayed with the matched observation and satellite data points marked (Fig. 34). This map can help the analyst to easily identify the region of interest. Time series plots of latitude, longitude, and relative error not only provide trend analysis, but also identify spatial and temporal outliers (Fig. 35). Two-variable plots focus on the comparison between satellite values and observed values (Fig. 36). For a perfect matchup, the scatterplot will be a straight line with a 45° angle and a correlation coefficient of 1. Relative error plots can help the analyst to graphically select data (Fig. 37).

The EVALUATION button on Fig. 34 prompts the analyst with another IDL GUI which contains more data selection criteria (Fig. 38). There are four pull-down menus in which data type, experiment, and investigator can have multiple selections, and the primary key menu can have only one selection. These pull-down lists are generated from valid records which are spatially and temporally defined via the GUI in Fig. 33. A valid range is listed for each data entry widget and can serve as a guide for specifying desired values. Data selection criteria, statistical results, and the final selected records may be saved into a file for reference.

The L2_QC button on Fig. 38 prompts the analyst to get the level-2 QC program. This allows the analyst to inspect a level-2 scene, or to reprocess the level-2 image for testing purposes.

5.4 DATABASES

At least two input files are needed to perform SeaWiFS derived product validation, one satellite file is identified

by the image database and one *in situ* file is identified by the *in situ* database. The field names for the database tables of the level-1 and -2 SeaWiFS image products and *in situ* data are listed in Tables 7, 8, and 9, respectively. Analyses can also produce two output files, one from the product validation matchup and one from the match-up evaluation.

Output files that store the results of these procedures can be identified easily using the field names in the database tables listed in Tables 10 and 11. Note that all the databases contain metadata, such as spatial and temporal information, which are used by the database to select the desired file paths and names.

5.5 CONCLUSIONS

Almost a decade after the end of the CZCS mission, the ocean research community has gleaned about as much as possible from that data set and is ready for the routine collection of global ocean color data. With a significantly improved sensor design and more systematic *in situ* observations, highly reliable data will be obtained. The sensor's performance will be carefully monitored to ensure that accurate calibrations are applied. To verify the accuracy of SeaWiFS derived products, the derived product validation software, discussed in this chapter, will be an important tool.

Results from the matchup between sea-truth measurements and satellite derived products will be used to assess the performance of the atmospheric correction and of the bio-optical algorithm. Information such as location, time, and viewing geometries, can assist scientists in identifying the limitations of proposed algorithms in order to improve their accuracy.

SeaWiFS Calibration and Validation Quality Control Procedures

GLOSSARY

AMT Atlantic Meridional Transect
 AQC Automatic Quality Control
 ASCII American Standard Code for Information Inter-
 change
 AU Astronomical Unit
 BATS Bermuda Atlantic Time-Series Station
 BBSR Bermuda Biological Station for Research
 BRDF Bidirectional Reflectance Distribution Function
 CALVAL Calibration and Validation computer system
 CHORS Center for Hydro-Optics and Remote Sensing
 CLM Climatological ancillary data file
 CVE Calibration and Validation Element
 CZCS Coastal Zone Solor Scanner
 DAAC Distributed Active Archive Center
 e-mail Electronic Mail
 FPA Focal Plane Assembly
 GAC Global Area Coverage
 GL SGI-specific Graphics Library
 GMT Greenwich Mean Time
 GSFC Goddard Space Flight Center
 GUI Graphical User Interface
 HDF Hierarchical Data Format
 HRPT High Resolution Picture Transmission
 IDL Interactive Data Language
 IGC Intergain Calibration
 IQC Interactive Quality Control
 LAC Local Area Coverage
 LAT Latitude
 LUN Lunar
 LUT Look-up Table
 L1 Level-1
 L1a Level-1a
 L1b Level-1b
 L2 Level-2
 L3 Level-3
 MLML Moss Landing Marine Laboratory (San Jose State
 University)
 MOBY Marine Optical Buoy
 MODIS Moderate Resolution Imaging Spectroradiometer
 NASA National Aeronautics and Space Administration
 nfs Network File Services
 NIST National Institute of Standards and Technology
 NMC National Meteorological Center
 NOAA National Oceanic and Atmospheric Administration
 NRT Near-Real Time
 OBS Observation
 OSC Orbital Sciences Corporation
 PML Plymouth Marine Laboratory
 QC Quality Control
 RE Relative Error
 ROI Region of Interest

SAA South Atlantic Anomaly
 SAT Satellite
 SDPS SeaWiFS Data Processing System
 SeaBASS SeaWiFS Bio-Optical Archive and Storage System
 SeaDAS SeaWiFS Data Analysis System
 SeaWiFS Sea-viewing Wide Field-of-view Sensor
 SGI Silicon Graphics Incorporated
 SOL Solar
 SST SeaWiFS Science Team
 SZA Solar Zenith Angle
 TDI Time Delay and Integration
 TIROS Television Infrared Observing Satellite
 TOVS TIROS Operational Vertical Sounder
 UCSB University of California at Santa Barbara
 UIM/X User Interface Management/X-Windows
 UNIX Not an acronym, but a computer operating system
 developed by Bell Laboratory.

SYMBOLS

L_{WN} Normalized water-leaving radiance.
 V_I *In situ* observation value.
 V_S Satellite observation value.
 λ Wavelength
 σ Standard deviation.

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13. ABSTRACT (Maximum 200 words) This document provides five brief reports that address several quality control procedures under the auspices of the Calibration and Validation Element (CVE) within the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) Project. Chapter 1 describes analyses of the 32 sensor engineering telemetry streams. Anomalies in any of the values may impact sensor performance in direct or indirect ways. The analyses are primarily examinations of parameter time series combined with statistical methods such as auto- and cross-correlation functions. Chapter 2 describes how the various onboard (solar and lunar) and vicarious (<i>in situ</i>) calibration data will be analyzed to quantify sensor degradation, if present. The analyses also include methods for detecting the influence of charged particles on sensor performance such as might be expected in the South Atlantic Anomaly (SAA). Chapter 3 discusses the quality control of the ancillary environmental data that are routinely received from other agencies or projects which are used in the atmospheric correction algorithm (total ozone, surface wind velocity, and surface pressure; surface relative humidity is also obtained, but is not used in the initial operational algorithm). Chapter 4 explains the procedures for screening level-1, level-2, and level-3 products. These quality control operations incorporate both automated and interactive procedures which check for file format errors (all levels), navigation offsets (level-1), mask and flag performance (level-2), and product anomalies (all levels). Finally, Chapter 5 discusses the match-up data set development for comparing SeaWiFS level-2 derived products with <i>in situ</i> observations, as well as the subsequent outlier analyses that will be used for evaluating error sources.				
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